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Monitoring of Sediments and Nonpoint Source Pollution Removal at the Spring Creek Wetland Project, Bowman-Haley Lake, North Dakota

by Charles W. Downer, Tommy E. Myers

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	<u>Task</u>		<u>Task</u>
CP	Critical Processes	RE	Restoration & Establishment
DE	Delineation & Evaluation	SM	Stewardship & Management

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by Charles W. Downer, Tommy E. Myers

U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

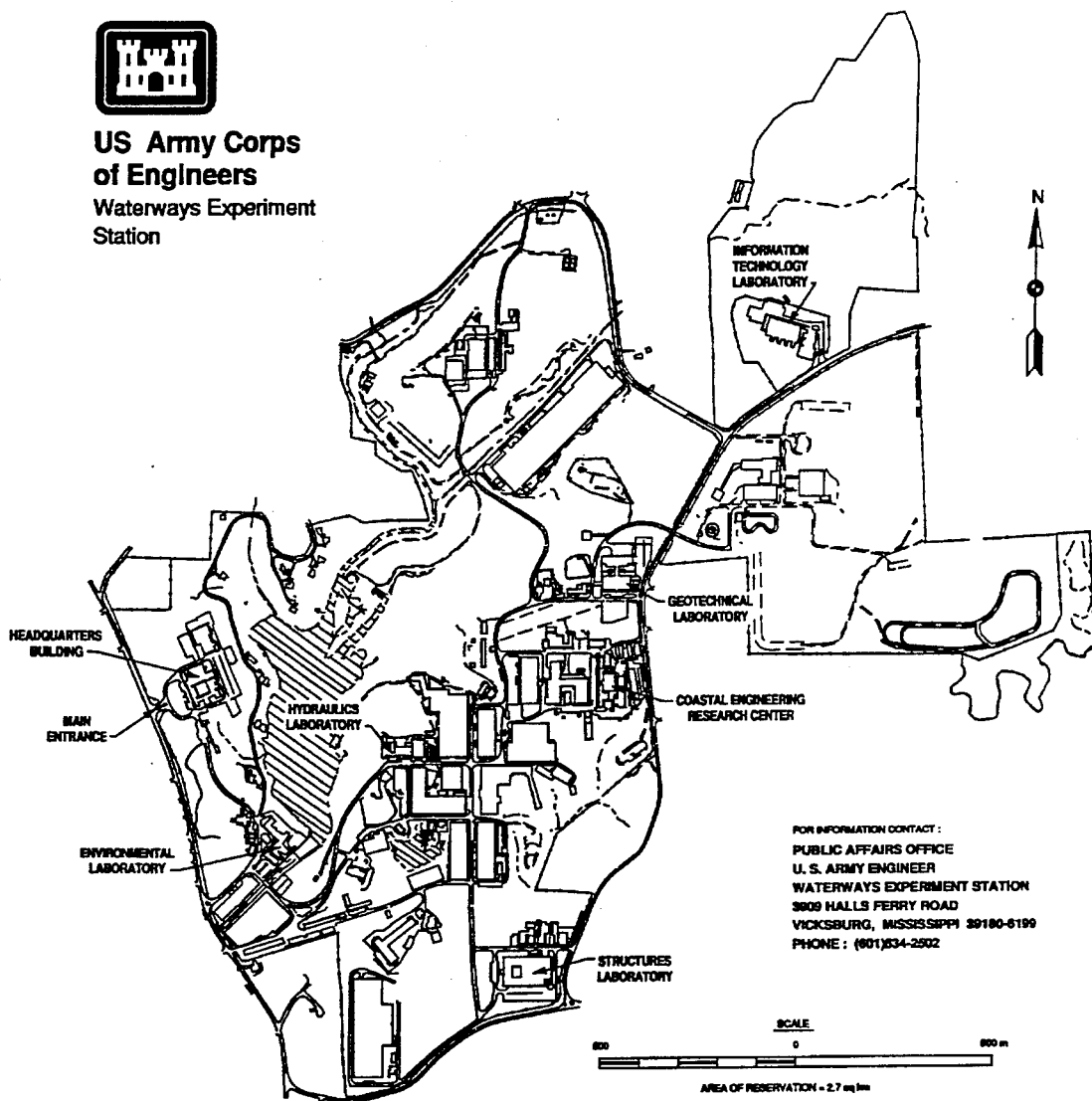
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Wetlands: Nonpoint Source Pollution Abatement

Monitoring of Sediments and Nonpoint Source Pollutant Removal at the Spring Creek Wetland Project, Boman-Haley Lake, North Dakota (TR WRP-SM-18)

ISSUE:

Nonpoint source pollution is a major contributor to water quality impairment in the surface waters of the United States. Since wetlands have an intrinsic ability to remove a wide spectrum of pollutants through a variety of processes, constructed wetlands potentially provide a cost-effective method for abating nonpoint source pollution. However, design guidelines for nonpoint source pollution abatement using constructed wetlands are not available—and information needed for design, pollutant removal efficiencies in particular—is sparse.

RESEARCH:

Water flow and sediment and pollutant (nitrogen and phosphorus) loadings associated with rainfall/runoff events were monitored at a 23.5-acre wetland in Bowman, North Dakota. Flows into and out of the wetland were continuously monitored and recorded with pressure gauges and data loggers. Water samples of influent and effluent were automatically sampled with programmable, flow-actuated samplers. Event hydrographs were prepared from the flow data, and event chemographs were prepared from the

chemical data. Removal efficiencies were calculated using mass balance analysis.

SUMMARY:

Suspended solids and total phosphorus removals were good (62 to 85 percent and 36 to 43 percent, respectively). Removal of nitrogen as total Kjeldahl nitrogen and nitrite + nitrate nitrogen was poor, generally 10 percent or less. Design and operation of the wetland for waterfowl nesting habitat limited the water quality enhancement function of the wetland.

AVAILABILITY OF REPORT:

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About the Authors:

Mr. Charles W. Downer is a research hydraulic engineer in the WES Hydraulics Laboratory and Mr. Tommy E. Myers is an environmental engineer in the WES Environmental Laboratory. Point of contact is Mr. Downer at (601) 634-2473.

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Preface

The work described in this report was authorized by Headquarters, U.S. Army Corps of Engineers (HQUSACE), as part of the Stewardship and Management Task Area of the Wetlands Research Program (WRP). The work was performed under Work Unit 32766, Wetland Stewardship and Management Demonstration Areas, for which Mr. Chester O. Martin, Environmental Laboratory (EL), U.S. Army Engineer Waterways Experiment Station (WES), was the Principal Investigator. Ms. Denise White (CECW-ON) was the WRP Technical Monitor for this work.

Mr. David Mathis (CERD-C) was the WRP Coordinator at the Directorate of Research and Development, HQUSACE; Dr. William L. Klesch (CECW-PO) served as the WRP Technical Monitor's Representative; Dr. Russell F. Theriot, WES, was the Wetlands Program Manager. Mr. Chester O. Martin, WES, was the Task Area Manager.

Participants in the study, in addition to the authors, included the Environmental Chemistry Branch, EL, WES, and Mr. Kent Belland, U.S. Department of Agriculture, Bowman, ND. Technical review of this report was provided by Drs. D. Dean Adrian of Louisiana State University, while on an Inter-agency Personnel Agreement at WES, and Mr. Kurt T. Preston, EL. This report was written by Mr. Charles W. Downer, Reservoir Water Quality Branch, Hydraulic Structures Division (HSD), Hydraulics Laboratory (HL), and Mr. Tommy E. Myers, Environmental Restoration Branch (ERB), Environmental Engineering Division (EED), EL, under the direct supervision of Mr. Glen A. Pickering, Chief, HSD, Mr. Daniel E. Averett, Acting Chief, ERB, and Mr. Norman R. Francingues, Jr., Acting Chief, EED, and under the general supervision of Mr. Frank A. Herrmann, Jr., Director, HL, and Dr. John Keeley, Director, EL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

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Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
acre-feet	1,233.489	cubic meters
cubic feet	0.02831685	cubic meters
degrees Fahrenheit	5/9	degrees Celsius or kelvins ¹
feet	0.3048	meters
gallons (U.S. liquid)	0.003785412	cubic meters
inches	0.0254	meters
miles (U.S. statute)	1.609347	kilometers
pounds (mass) per cubic foot	16.01846	kilograms per cubic meter
square miles	2,589.998	square meters
¹ To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9) (F-32)$. To obtain kelvin (K) readings, use: $K = (5/9) (F-32) + 273.15$.		

1 Introduction

Bowman-Haley Reservoir is a popular lake located along the western part of the North Dakota/South Dakota border. The lake was constructed in 1966 as a flood control and water supply reservoir. Although little of the water in the lake has been used for water supply, the lake became a popular recreation area due to a general lack of water-related activities available in the semiarid region. The lake initially had good water quality; however, as the lake aged, water quality declined. Suspended solids, excess nutrients and corresponding turbidity, excess algae growth, and low winter dissolved oxygen concentrations are the main concerns. Recreational use of the lake has also declined.

The local Soil Conservation Service developed a plan to improve the water quality of the reservoir (Soil Conservation Service 1990) which primarily consists of reducing nonpoint source pollution through good agricultural land management. In addition, a 23-acre¹ wetland was constructed in 1991 on Spring Creek with the dual purposes of water quality enhancement and creation of waterfowl nesting habitat. The wetland was constructed on U. S. Army Corps of Engineers (USACE) lands upstream of the reservoir by the Bowman Slope Soil Conservation District and Ducks Unlimited.

As part of the USACE Wetlands Research Program (WRP), the U. S. Army Engineer Waterways Experiment Station (WES) monitored wetland flows, suspended solids, nutrients, and herbicides from May 1992 through October 1993. Sampling efforts concentrated on infrequent late spring/early summer rainfall events. Over 300 samples were collected and analyzed during each spring/summer sampling period. The wetland was also monitored for the accumulation of sediments on both feldspar pads and Plexiglas disks.

The monitoring program was intended to demonstrate the ability of constructed wetlands to retain suspended solids and other nonpoint source pollutants. Pollutant removal efficiencies were to be calculated from the flow and concentration data. These removal efficiencies, combined with information on hydraulic retention time, may then be useful in the design of other constructed wetland projects.

¹ A table of factors for converting non-SI units of measurement to SI can be found on page viii.

2 Site Description

Bowman-Haley Lake

Bowman-Haley Reservoir is a 1,750-acre USACE flood control/water supply lake located along the western part of the North Dakota/South Dakota border (Figure 1). The average annual inflow into the reservoir is 30 cfs. The lake has a drainage area of approximately 500 square miles of gently sloping lands known as the Missouri Plateau. The land rises to the west, reaching elevations of over 3,000 ft. Most of the land contained in the watershed is devoted to different agricultural practices with approximately half of the available acreage in crops and half being used as range land.

Spring Creek

Spring Creek is one of three major tributaries that flow into the reservoir. The drainage area for the creek is approximately 186 square miles. Spring Creek is ungauged, but average annual inflow is probably proportional to the size of the drainage basin, or around 11 cfs. Spring Creek has a small annual baseflow, on the order of 1 cfs, and has periods of high flow after intense late spring/early summer storm events. The creek may also have high spring flows due to snow melt, depending on the winter accumulation of snow. The Spring Creek drainage basin is also almost entirely agricultural land and includes the town of Bowman, population 2071.

Spring Creek Wetland Project

The wetland is located within the flood control pool (el 2770¹) of the reservoir along Spring Creek (Figure 1). The wetland was built in a naturally occurring low area and is connected to Spring Creek with a 2,500-ft constructed diversion channel (Figure 2). Flow into the wetland is controlled with an 18-in.-diam, gated, 58-ft-long corrugated metal culvert located between Spring Creek and the diversion channel. The water level in Spring

¹ All elevations (el) cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

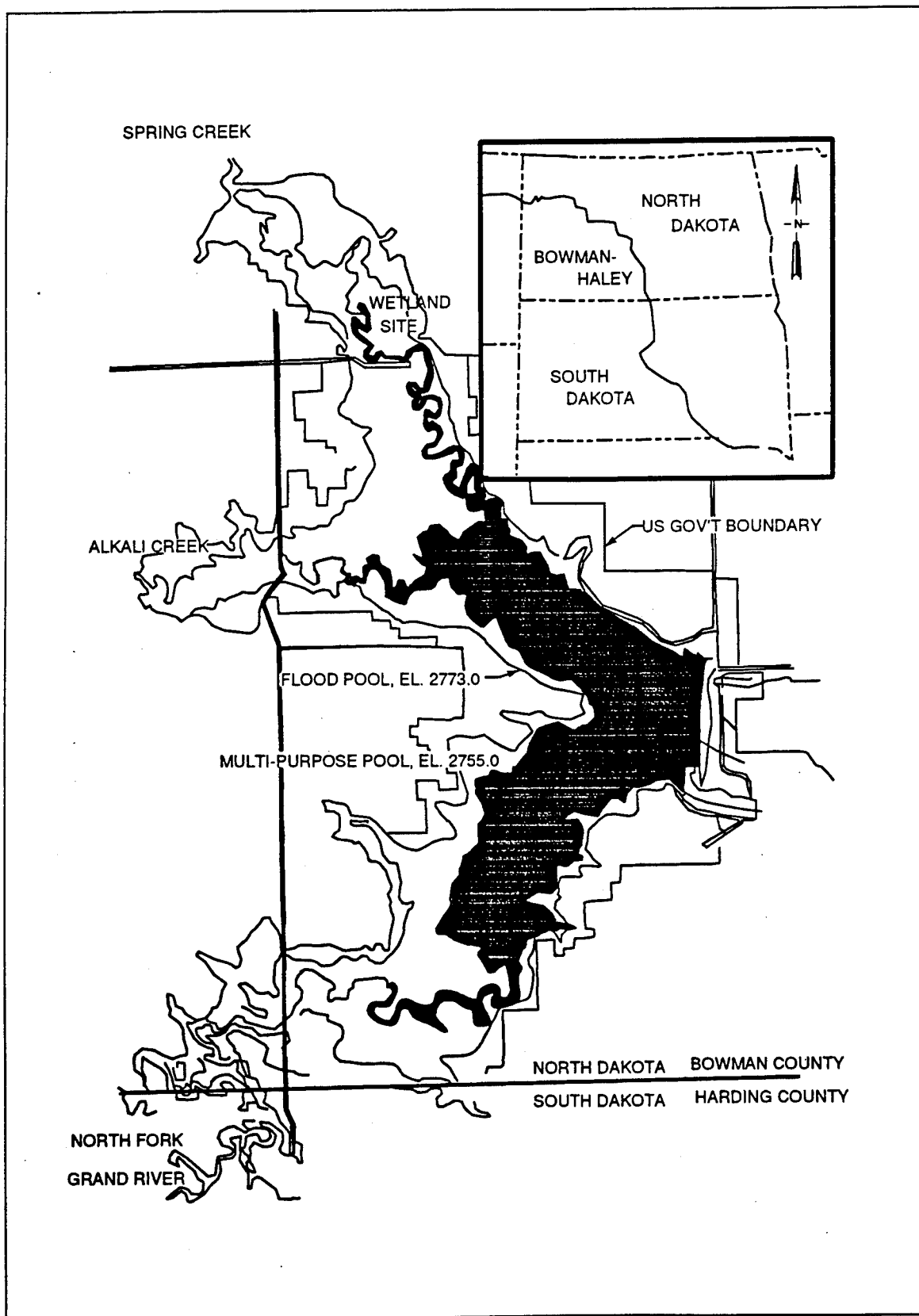


Figure 1. Location of Bowman-Haley Reservoir

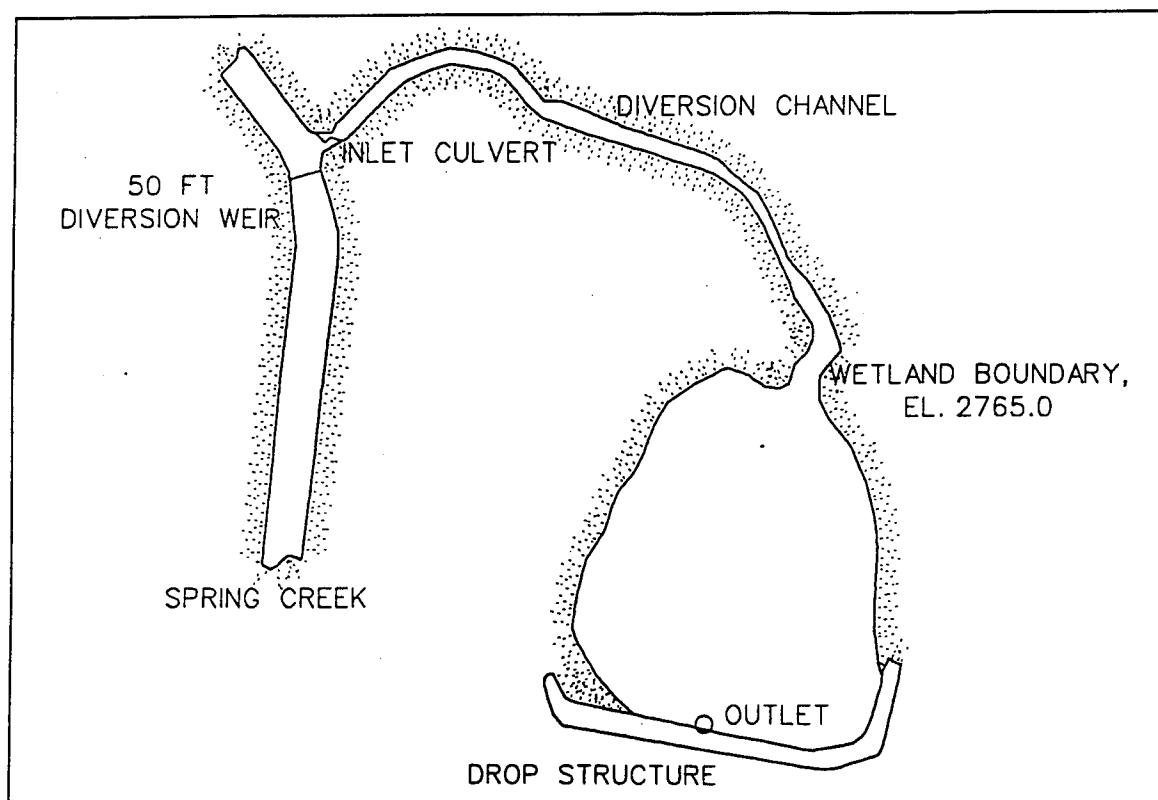


Figure 2. Spring Creek wetland site

Creek is controlled with a 50.8-ft weir with two end contractions located just downstream of the wetland inlet. The weir has a 100-cfs flow capacity.¹ The top of the weir is at el 2765.0. Stop logs in the center of the weir allow the creek to be drawn down to el 2762.0, the same level as the bottom of the diversion channel. Flow out of the wetland is controlled by a 48-in.-diam drop structure, also located at el 2765.0.

At el 2765.0, the wetland area, including the diversion channel, is approximately 23.5 acres and the volume is approximately 46.6 acre-ft. The following area capacity data were taken from Ducks Unlimited drawings. Areas and volumes were calculated at 1-ft intervals using AUTOCAD software. Areas and volumes include the diversion channel.

The wetland is operated by the North Dakota Game and Fish Department to maximize waterfowl usage. The wetland is filled with spring or early summer runoff as soon as possible by installing all of the stop logs in the Spring Creek diversion weir. Once full, water is held in the wetland until late summer. Flows are allowed to pass through the full wetland. In late summer/early fall, the stop logs in the diversion weir are removed and the

¹ Personal Communication, 1991, Rodger Smith, Hydrologist, Ducks Unlimited, Bismarck, North Dakota.

Table 1 Area/Capacity Data for the Spring Creek Wetland		
Elevation	Area acres	Capacity acre-ft
2761.0	0.00	0.00
2762.0	4.75	2.37
2763.0	11.91	10.70
2764.0	19.11	26.21
2765.0	23.54	46.60
2766.0	25.14	70.94

wetland is drawn down to el 2762.0, leaving only a very small amount of water in the wetland. The remaining water is subject to seepage and evaporation, and the wetland is dry or has very little water going into the winter.

Climate

The southwest corner of North Dakota is a semiarid region. Total yearly precipitation at the Bowman courthouse is only 15.5 in. (National Oceanic and Atmospheric Administration (NOAA) 1992). Most of the rainfall in the region occurs in May, June, and July, comprising 8.2 inches, 53 percent of the total yearly precipitation. The rainfall during this period is primarily due to infrequent heavy thunderstorms, which tend to be localized, intense, and with frequent lightning. Snowfall typically evaporates before spring thaw. Average monthly precipitation is shown in Figure 3.

Evaporation, as measured at the Dickinson Experiment Station, was 37.54 in. in 1992, for the months of May through September (NOAA 1992). No measurements were available for other months when temperatures are typically below freezing. The average annual temperature at the Bowman courthouse is 42.5 °F (NOAA 1992). Typically, the first freeze occurs in early October and the last freeze occurs in May. Winter temperatures dip to 40 deg below zero. Although the winters tend to be very cold, summertime highs are often above 90 °F. Average monthly temperatures are shown in Figure 4. Average wind speed is 11 mph, and the winds are predominately west, northwest.

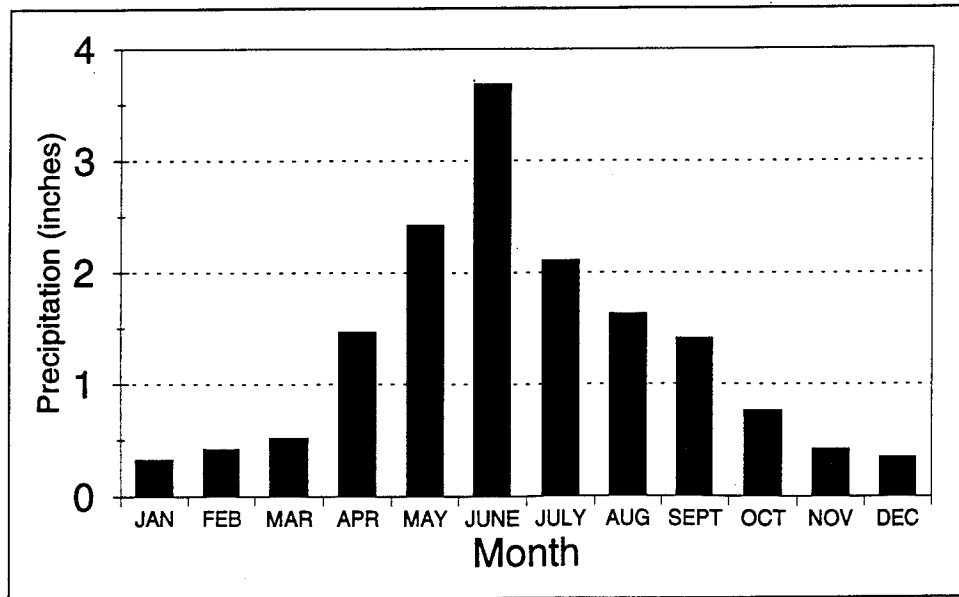


Figure 3. Average monthly precipitation at Bowman, ND

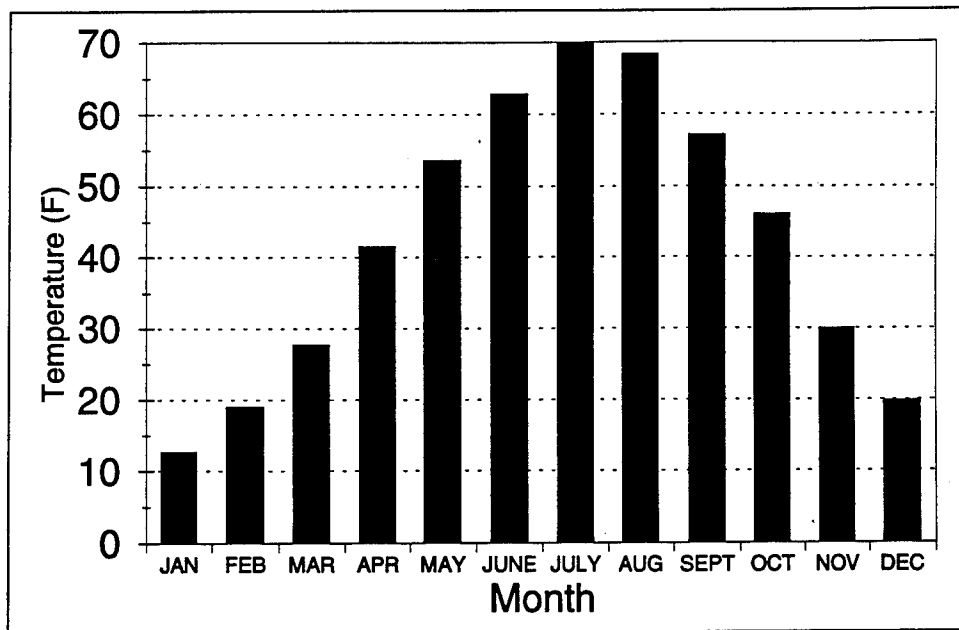


Figure 4. Average monthly temperature at Bowman, ND

Soils

Soils in the region are generally described as nearly level to gently sloping, deep to moderately deep, and moderately well-drained and well-drained loamy

soils that have a clay pan. The principal associations are Belfield-Rhoades-Amor and Rhoades-Moreau. Soils in the area are approximately 3 ft deep and consist of a grayish-brown surface layer 3 to 8 in. thick underlain by a sub-surface of grayish-brown to light-grayish-brown silt and clay loams. The soils overlay soft shale and sandstone. The soils are moderately organic.

The wetland is located on Rhoades Complex, terrace soils. These soils are deeper, typically highly saline, and have very slow permeability. The subsoil is extremely firm silty clay that contains salt masses, which overlies silty clay loam over soft shale. Information on soils was obtained from the U.S. Department of Agriculture (USDA) (1975).

Water Quality

Bowman-Haley reservoir is a eutrophic lake which experiences intense and chronic algae blooms during the summer months and low dissolved oxygen concentrations during the winter freeze. During summer and fall, persistent winds keep the reservoir well mixed, and dissolved oxygen concentrations typically exceed the state's minimum water quality criterion of 5 mg/L. The lake becomes stratified during the winter. Under these stratified conditions, low dissolved oxygen results from oxygen-demanding bottom sediments. The oxygen demand is believed to originate from the decay of excess algae after they die and settle to the bottom. Excess nutrients are believed to originate from agricultural practices. Water quality testing by the USACE (USACE 1984) in the lake and its tributaries shows exceedances of state and Federal water quality criteria for both ammonia and phosphorus.

Macrophyte growth is limited to emergent species in the shallow upper reaches of the reservoir arms. No submergent aquatic vegetation is found in the deeper portions of the lake. The lake's high turbidity is thought to inhibit the growth of submerged aquatic vegetation.

The lake also has high concentrations of dissolved solids with numerous exceedances of Federal water quality criteria for iron and sulfates. The dissolved solids are a result of natural conditions in the region. The lake showed a trend for increasing dissolved solids concentrations, which is due to a lack of dilution of the dissolved constituents (USACE 1984). As the level of salts in the lake increases, the bottom layer of water will become denser and may eventually become permanently stagnant. Removal of the bottom layer of water by selective withdrawal may prevent this situation.

The lake and inflows also have high concentrations of heavy metals; testing of the inflow and the reservoir showed exceedances of state and Federal water quality criteria for metals, including mercury, arsenic, copper, and nickel, which are highly toxic to aquatic organisms at very low concentrations. The lake and major tributaries also experience periods of low pH.

3 Materials and Methods

Flow Measurement and Water Quality Sampling

Instrumentation was installed at the inlet and outlet structures, with the intent of intensive sampling of storm runoff hydrographs. Originally, one ISCO 3700 automatic sampler and one Steven's differential pressure probe and data logger were installed at both the inlet and outlet (Figure 5). The ISCO sampler was equipped with a flow actuator which sensed the presence of water and actuated the sampler when water was present. Due to problems with the Steven's data logger at the inlet during the 1992 sampling year, it was replaced with an ISCO differential pressure transducer and flowmeter in the 1993 sampling year. The ISCO flowmeter was directly attached to the ISCO automatic sampler, and the sampler was activated by the flowmeter, based on water level.

The instrumentation for the inlet is shown in Figure 6. The intake to the sampler was located at the center of the inlet pipe at el 2762.75. The flow actuator was located in the inlet canal above the inlet at el 2762.77. The flow actuator was moved up or down, as needed, depending on water level conditions and sampling requirements. The pressure transducer was located on the sill of the inlet structure at el 2762.5. A staff gauge was placed in the control structure stilling basin and used as a check and backup to other water level measurements.

The instrumentation for the outlet structure is shown in Figure 7. The intake to the sampler and pressure probe was located approximately 50 ft from the outlet structure at el 2764.3 and 2764.1, respectively. The flow actuator was located approximately 20 ft from the outlet structure at el 2765.0, the same elevation as the top of the outlet structure. The flow actuator was moved up and down as water level conditions and sampling requirements changed. A staff gauge was placed at the same location as the flow actuator, at el 2764.5.

The combination of pressure probes and data loggers recorded the depth of water above the probe every 15 min. The readings were stored on a data card that was either sent back to the laboratory or downloaded in the field with the use of a notebook PC. Accuracy of the system was 1 percent of full scale.

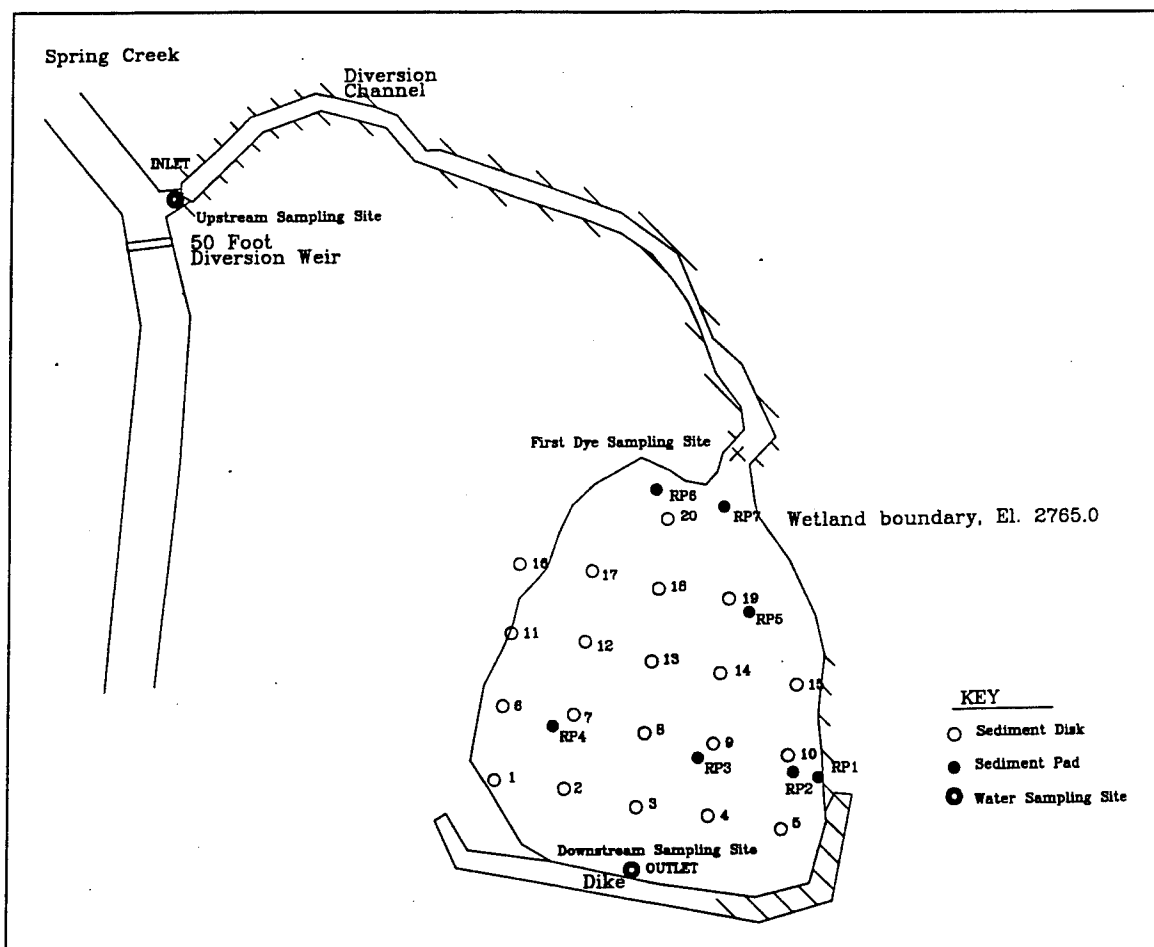


Figure 5. Sampling locations

For the 5-ft range of the probes used, accuracy was 0.05 ft, or 1.5 cm. The probes were calibrated in 2 ft of water before installation. The differential pressure transducers automatically adjusted for changes in atmospheric pressure.

Upon activation, the automatic samplers were programmed to collect twenty-four 300-ml samples over a 24-hr period. It was anticipated that the water level in the creek and the pollutant loadings would rise rapidly. Because of this, the bulk of the 24 samples was collected soon after sampler activation. As time progressed the sampling interval was lengthened.

The program worked on the following schedule:

- a. One sample upon activation.
- b. Two samples at 15-min intervals.
- c. Nine samples at 30-min intervals.

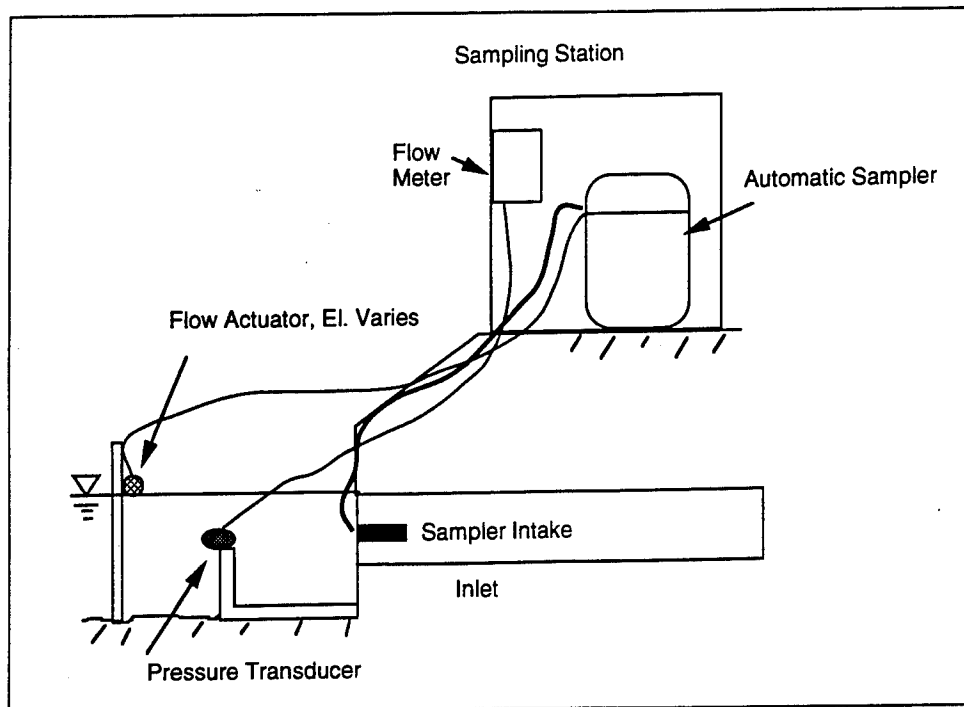


Figure 6. Spring Creek wetland inlet sampling

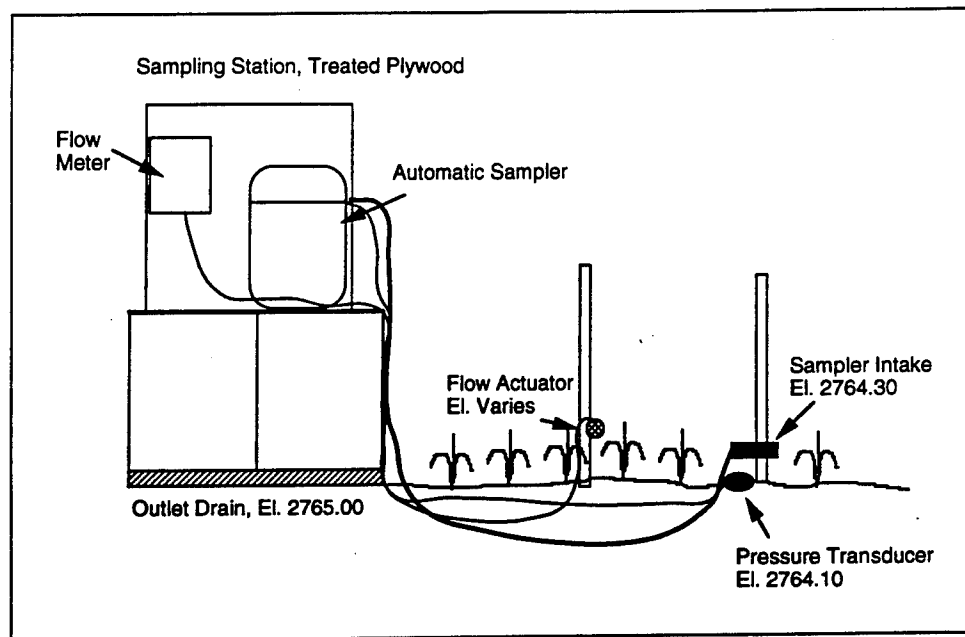


Figure 7. Spring Creek wetland outlet sampling

d. Twelve samples at 90-min intervals.

At the end of the 24-hr period, the samples were removed from the sampler and transferred to another set of sample bottles left at the Bowman-Slope Soil Conservation District (SCD) office. At that time the same program

could be run again, or a 2-day program (which collected a sample every 2 hr), or 3-day program (which collected a sample every 3 hr) could be run, depending on the available flow. The 1-, 2-, and 3-day programs were stored in the sampler as programs 1, 2, and 3, and SCD personnel determined which program to run based on conditions. A 5-day program was later added to the sampler's memory.

The automatic samplers were powered by 12-V batteries. Due to the power drain on the battery from the sampler constantly awaiting activation, a solar panel was installed with each of the samplers to keep the batteries charged. Originally the data loggers were powered by a 12-V battery without a solar panel. After encountering problems with the batteries during the 1992 sampling period, a solar panel was installed at each site to keep the batteries charged. The instruments were protected from the weather and vandalism by separate waterproof containers and were locked inside wooden sampling sheds constructed of treated plywood.

Arrangements were made through the SCD to have a person available to perform routine maintenance on the equipment and handle the collection, transfer, and shipping of samples. After a storm event, samples were collected and sent back to the WES as soon as possible, usually the same day by overnight service. Samples were kept on ice until shipping, and were packed in ice for shipping. Each sample was identified by noting its position in the sampler and the time it was collected on the bottle with a permanent marker. Information regarding sampling results, including the time each sample was taken and any problems encountered, could be accessed through the display mode of the sampler. This information was recorded and sent along with the sample bottles on data sheets provided to SCD personnel. In addition to this information, the staff gauge and data logger readings at the time of sample collection were recorded.

Routine checks of the equipment consisted of making sure that both units at each location were operating properly. For the automatic sampler, the display would indicate that the sampler was in the master/slave mode awaiting the master (flow actuator). The data loggers were checked to see that they would activate upon pushing the select button, and the stage reading on the data logger was checked against the reading on the staff gauge. The date and time were also checked. This information was recorded and any problem corrected and noted. If a problem arose that could not be corrected by SCD personnel, WES personnel were notified. After checking the equipment, the covers were closed and the sampling stations locked. Instruments were checked biweekly, and immediately before an anticipated storm event. Also, the intake line to the sampler was inspected for wear, corrosion, and algae or mold growth. If the line was not in proper condition, it was replaced with new line, also available at the SCD office. Cables for the actuator and pressure probe were also inspected.

Flow Calculations

Flows into the wetland were calculated using the recorded water levels and a FORTRAN program written to determine flow through culverts. Culvert flow was determined from Carter (1957) methods where flow is calculated based on the flow regime and associated discharge coefficients. In addition to calculating inflow, the program tracked the volume of water entering the wetland, water elevation in the wetland (based on the area capacity data in Table 1), and discharge. Discharge was calculated by treating the riser pipe as a sharp crested weir and using the appropriate discharge equations (Chow 1959). The discharge coefficient for the outlet structure was determined by taking flow measurements at the outlet pipe with a Marsh McBurney velocity meter. Daily rainfall and evaporation as recorded at Bowman were used in the program to calculate 1992 water levels and flows. Hourly rainfall and evaporation, recorded at the wetland site, were used during the 1993 calculations. Because of widely conflicting correction coefficients in the literature for correcting pan evaporation, pan evaporation was input directly. Literature values suggest that this approximation could be as much as 20 percent off in either direction.

Flows over the weir in Spring Creek were estimated from the upstream water surface elevations and the broad crested weir equation (Chow 1959).

Sediment Accretion Measurement

Techniques

Sediment accretion in the wetland was measured using two different techniques: feldspar pads and Plexiglas sediment disks. Feldspar is a white clay that is commercially available as a fine white powder. Once saturated, the feldspar pads solidify and provide an easily identifiable white horizon in the soil column. Prior to construction of the wetland in 1991, eight feldspar pads were placed in the wetland along two different transects (Figure 5). Feldspar pads are shown as dark circles in Figure 5. The feldspar pads were approximately 0.25 m square and 1.5 cm thick. The feldspar pads were marked with a metal fence post on the southwest corner of the pad. Prior to the 1993 sampling period, 20 Plexiglas sediment disks, 0.5 cm thick, with a 100-cm² surface area, were placed on an approximate 200-ft by 200-ft grid (Figure 5). Plexiglas disks are shown in Figure 5 as light circles. The surfaces of the disks were roughened with sandpaper to provide a more natural texture. The Plexiglas disks were marked with a metal rod that was driven through a 2-cm-diam hole in the center of the disks.

Sampling

Both the feldspar pads and Plexiglas disks were sampled after the 1993 water quality sampling period ended and the wetland water was drawn down. Seven of the original eight feldspar pads were found and sampled. Samples from the feldspar pads were collected using tin cans as corers. Two to four cores were collected from each pad located. Samples were wrapped in parafilm and transported back to the laboratory for analysis. Some of the pads were submerged under water 1 to 6 in. deep, but this did not hamper sampling. Wet samples were frozen before analysis. Cores were cut in half, and the sediment accretion above the white horizon was measured to the nearest 0.1 mm with a dial caliper in several places. The average of the measurements was taken as the sediment accretion.

All but one of the 20 sediment disks were found and sampled. Some of the disks were located in the remaining shallow water. It was apparent that in removing the disks from the water some of the sediments on the edges of the disk washed off. However, this did not seem to happen at the center of the disk. For this reason, depth accretion measurements on these disks should remain accurate while total sediment accumulation by weight will be slightly underestimated.

The sediment disks were collected and sediment accretion above the disks was measured to the nearest 0.1 mm in the field. Several measurements were taken and then averaged. The disks were then put in ziplock bags and transported back to the WES. Portions of the samples were dried at 105 °C to determine dry weight. Selected samples were also dried at 550 °C to determine the volatile, organic content.

Climatological Conditions

For the 1992 sampling period, rainfall measured at Bowman and evaporation measured at Dickinson were obtained from NOAA data. Because of the localized nature of summer storm events in the region, it was desirable to make direct measurements of rainfall at the wetland site. In order to get a better water balance for the system for the 1993 sampling period, a weather station was installed near the wetland inlet. The weather station recorded rainfall, evaporation, temperature, relative humidity, solar radiation, and wind speed. Rainfall was measured with a tipping bucket gauge. Evaporation was measured in a Class A evaporation pan. The level in the pan was monitored with a float gauge in a stilling basin. All readings were recorded electronically every 60 min. Temperature, relative humidity, solar radiation, and wind speed readings were taken every 60 sec and the average recorded every 60 min.

Analytical Chemistry

Total suspended solids were determined gravimetrically, nitrate-nitrite nitrogen by colorimetric automated cadmium reduction (U.S. Environmental Protection Agency 1979, Method 353.2), total Kjeldahl nitrogen by colorimetric automated phenate (U.S. Environmental Protection Agency 1979, Method 351.2), total phosphorus by persulfate oxidation followed by colorimetric ascorbic acid (U.S. Environmental Protection Agency 1979, Method 365.3), and sulfate by colorimetric, automated methylthymol blue (U.S. Environmental Protection Agency 1979, Method 375.2). Herbicides were determined using the enzyme-linked immunosorbent assay technique described in Myers and Myers (1992).

4 Results and Discussion

Climatological Conditions

Climatological conditions preceding and including the sampling period are shown in Figures 8-10. As previously described, prior to May of 1993, measurements of precipitation and temperature were taken from NOAA data collected at Bowman and evaporation data collected at Dickinson. From May 10 to September 11, climatological data were collected at the site. As shown in Figure 8, snowfall in late 1991 and early 1992 was below normal. Because of this, little spring runoff occurred in the spring of 1992, and the wetland was dry going into the sampling period. Conversely, snowfall the following year was unusually high, and approximately 8 in. of snow remained on the ground when the spring thaw began (NOAA 1992). Spring thaw runoff was sufficient to fill the wetland. Rainfall for the summer months was typical of local conditions. Summer temperatures in 1992 were somewhat above normal, and summer temperatures in 1993 were slightly below normal (Figure 9). Evaporation measured at Bowman in 1992 was normal, while evaporation measured at the site in 1993 was below normal (Figure 10). The value for July at Spring Creek seems particularly low; yet, July rainfall at Spring Creek, while not abnormally high, was light and frequent, and may have hampered evaporation at the site. Rainfall was recorded on 23 of the 31 days in July. Evaporation measured at Dickinson, approximately 80 miles northeast of the site, was significantly higher for the same period. Evaporation measured at Dickinson for the period June through August was 6.36, 6.63, and 6.41 in., respectively.

Climatological conditions measured at Bowman during the 1993 sampling period are summarized in Table 2.

Water Levels and Flows

The wetland was initially dry after construction was complete in 1992. Monitoring of the wetland began in May 1992. The first significant storm event occurred on June 20, which partially filled the wetland. The next significant rainfall event occurred on July 11, which completed filling the wetland and caused a short duration discharge. No other significant rainfall

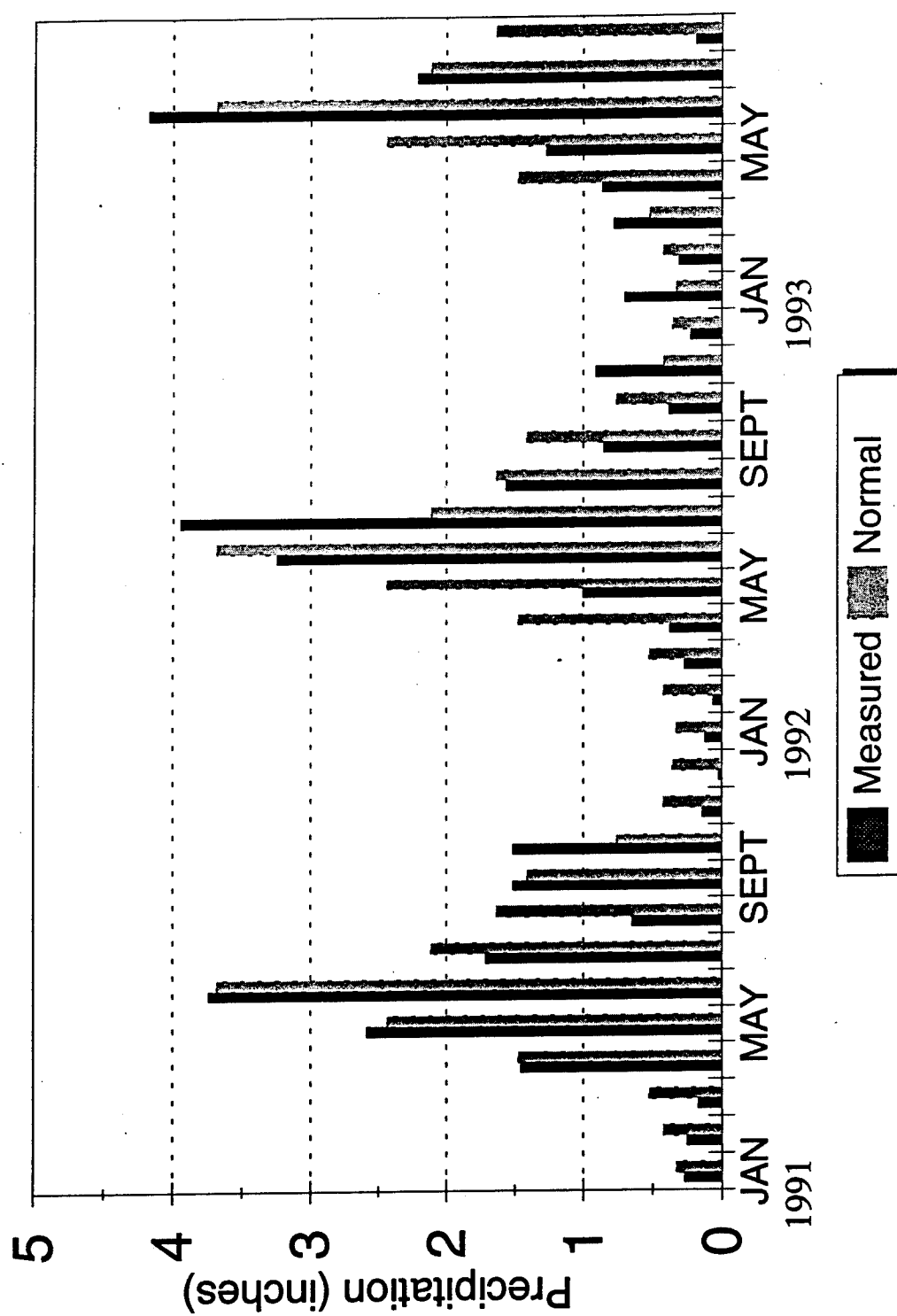


Figure 8. Monthly precipitation at Bowman, ND, Jan 1991 - Aug 1993

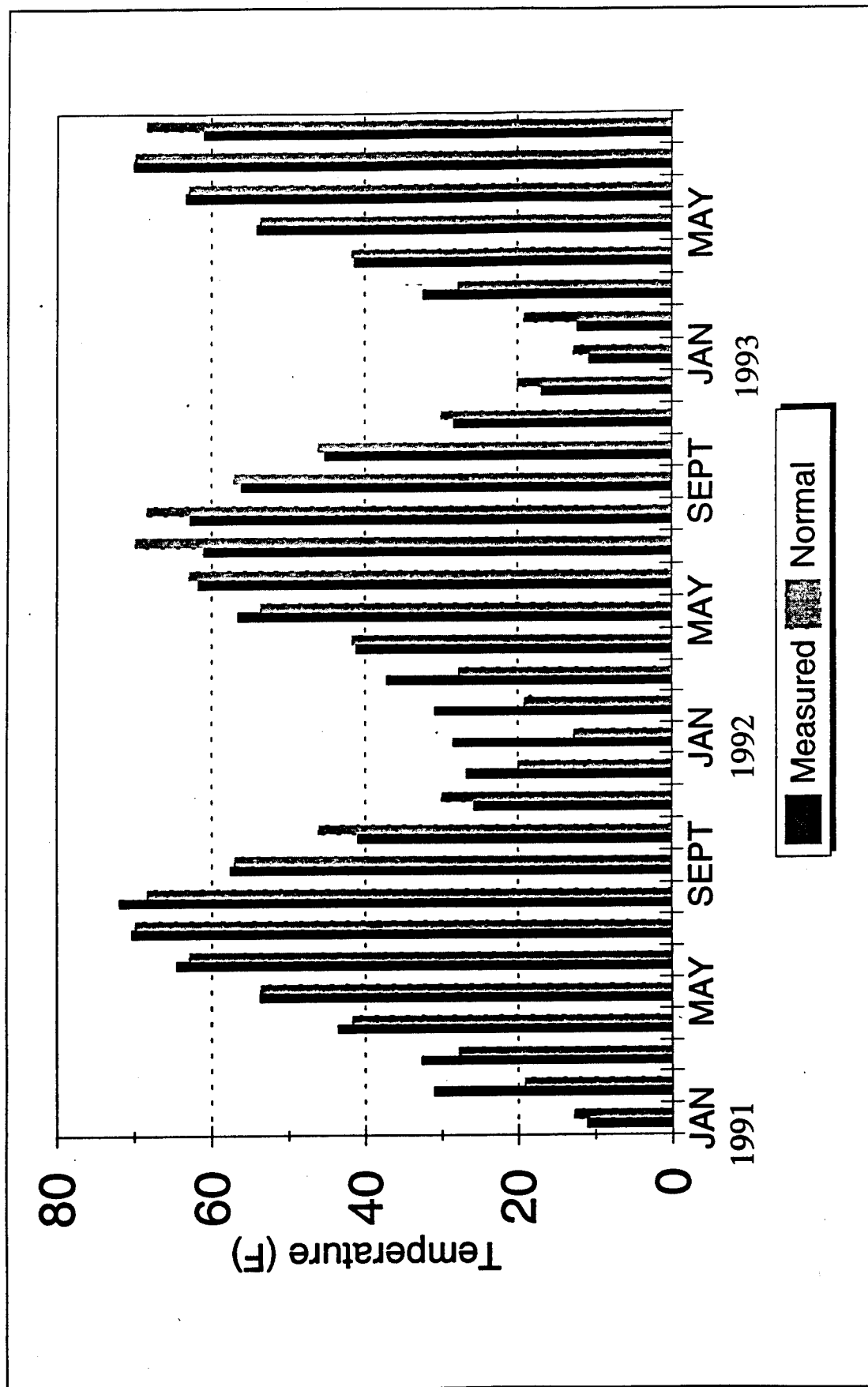


Figure 9. Average monthly temperature at Bowman, ND, Jan 1991 - Aug 1993

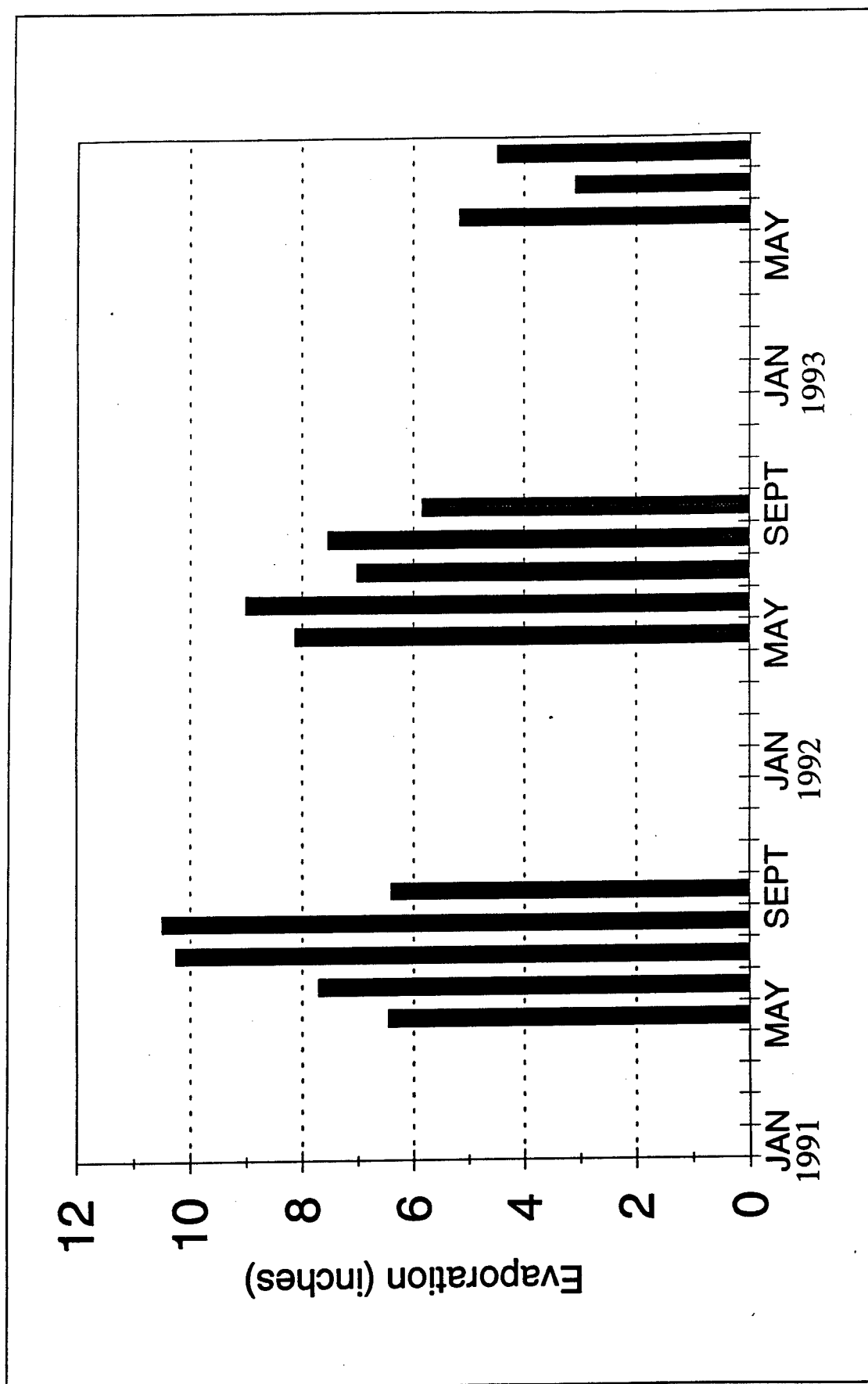


Table 2
Climatological Conditions as Measured at Spring Creek, 1993

Sampling Period	Temperature, °F	Relative Humidity %	Wind Speed mph	Rainfall in.	Evaporation in.
Totals/Avg.	60.2	63	9.1	6.04	14.8
May ¹	54.4	57.4	9.5	0.28	2.91
June	59.2	59.2	10.6	3.33	4.33
July	62.4	62.4	9.2	2.21	1.76
August	64.3	64.3	8.0	0.18	4.31
September ¹	54.8	54.8	7.1	0.05	1.52
¹ Data for partial month.					

events occurred during the 1992 sampling period. After the storm waters receded, the wetland water level started to fall. The wetland water level was monitored until September 10.

Problems with the Stevens data loggers occurred from July 11-22. The data loggers were recording readings that were obviously in error. It is thought that frequent lightning associated with the July 10 storm event caused the problems. The units were serviced and returned. Alternate units were used during their absence. Although the problem was corrected, no water elevations were recorded during this significant rainfall. In order to try to fill this void, a hydrologic study of the rainfall event was conducted.

Rainfall of the associated event totaled 1.62 in. (as measured at Bowman, ND); the drainage area of the basin is 186 square miles, and the maximum stream length is approximately 24 miles. A synthetic unit hydrograph was calculated using Snyder's method (Linsley, Kohler, and Paulhus 1982). Coefficients were determined from the nearest unaltered gauged stream, Cedar Creek, which is approximately 35 miles northeast of the site. The drainage area of the gauged basin is 553 square miles, and the stream length is approximately 54 miles. Coefficients for this stream were determined from an isolated May 1986 storm which produced an average rainfall of 2.0 in. at the nearest precipitation gauges (Amigdon, Reeder, and Hettinger) and a classic runoff hydrograph shown in Figure 11.

As shown in this figure the peak discharge (Q_p) of 260 cfs occurred at the time of peak T_p , which was 4 days after the rainfall. Runoff was separated from the base flow, and Q_p and T_p were used to construct the dimensionless hydrograph shown in Figure 12.

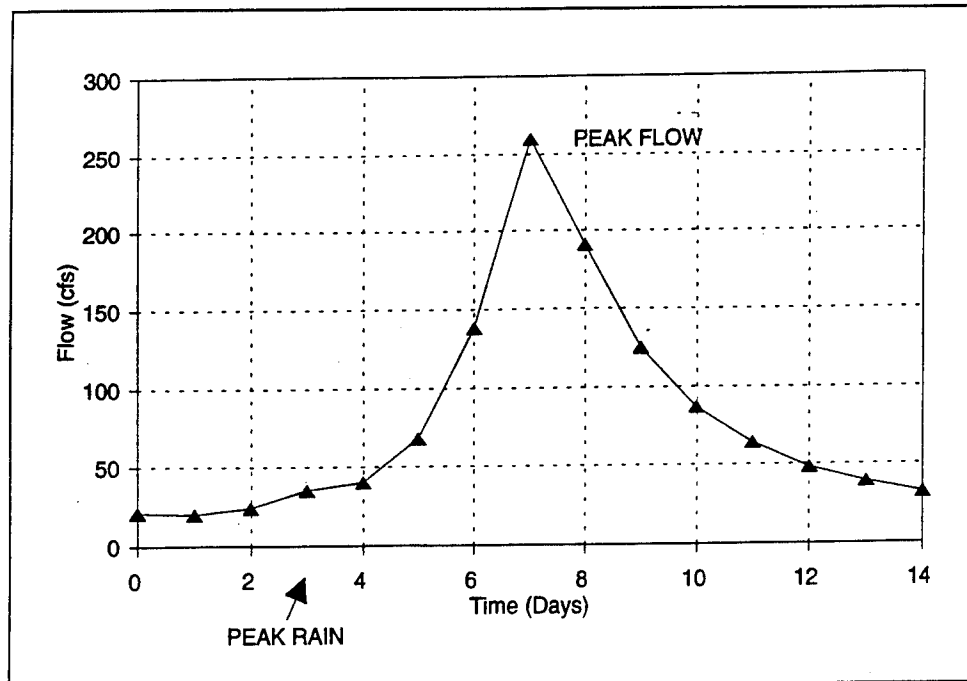


Figure 11. Cedar Creek runoff hydrograph for May 1986 storm event

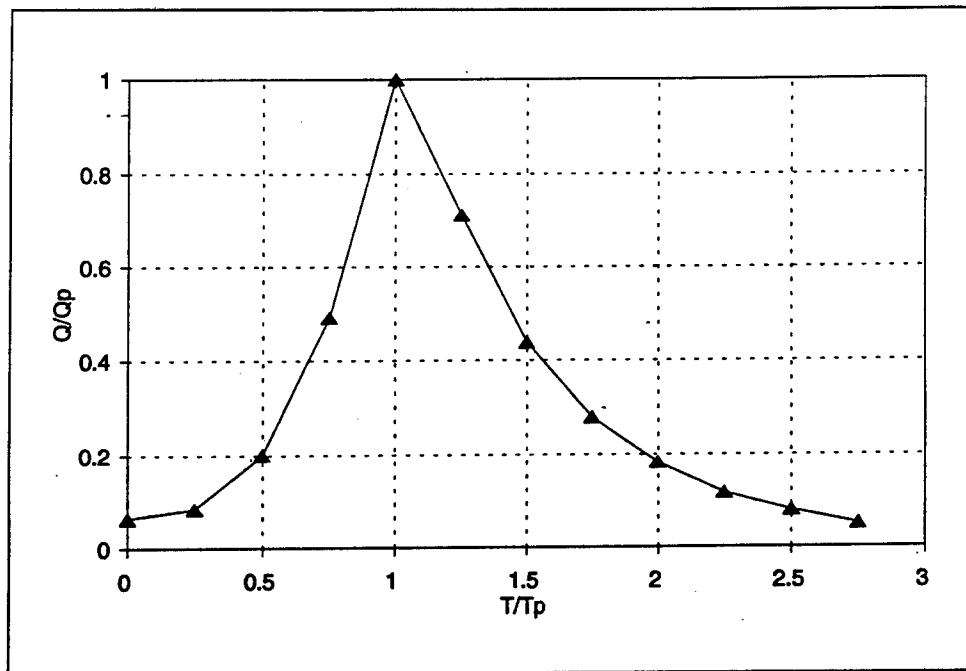


Figure 12. Cedar Creek dimensionless hydrograph

The assumptions applied in the following analysis are:

- a. All storms in a basin will produce a similar hydrograph, i.e., all runoff events can be derived from the dimensionless hydrograph.
- b. Basins of similar shape, slope characteristics, land use, and coverage will produce similar hydrographs whose characteristics, Q_p , T_p , and T (duration of the hydrograph) can be determined based on drainage area (DA), stream length (L) and basin shape, which is defined by the length from the basin outlet to a point opposite the basin centroid L_c .

Based on these assumptions, a runoff hydrograph was calculated for the July 10 rainfall event at Spring Creek. Important parameters for the hydrograph are: T_p is 60 hr, Q_p is 61 cfs, and T is approximately 7 days. The Spring Creek hydrograph is shown in Figure 13.

The preceding analysis yields only an estimate of runoff produced from the storm event. The necessary information in the wetland flow calculation program is head upstream of the wetland. Therefore, the flow in the creek must be converted to head. Because of the large diversion weir located immediately downstream of the diversion channel, head could be estimated using a broad crested weir equation. However, two circumstances prevented the direct application of the broad crested weir equation to derive heads: first, there was the storage capacity of Spring Creek upstream of the weir; and secondly, flow into the wetland through the inlet culvert must be subtracted from the stream flow before calculating a head. Since the flow into the culvert is dependent on the head, this must be a circular calculation. Taking this into consideration, the stream elevations shown in Figure 14 were calculated.

Due to the high capacity diversion weir in place, head above the weir at peak flow was only 0.53 ft. Head above the culvert invert ranged from 1.29 ft at the beginning of the storm to 3.53 ft at the end of the storm. Tail-water elevation varied from 1.29 to 3.05 ft. After filling the stream's storage capacity, water elevations in the stream varied only 0.5 ft. Because of the control structures in place, relatively large errors in runoff calculations will result in only small errors in head and still smaller errors in inflow. However, because of the inexact methods used to calculate these flows, they should be considered rough estimates which may be useful for helping define trends in the water quality data.

With the gaps in the upstream head data filled, wetland inflows and outflow were calculated as shown in Figure 15. Wetland water elevations are shown in Figure 16.

Monitoring of the wetland resumed on May 14, 1993. By the time sampling had begun, spring thaw had occurred and the wetland was already full and overflowing. Sampling was delayed until May to avoid possible damage to instruments due to late freezes. Also, the intent of sampling was to monitor wetland treatment effectiveness during storm events. Water levels in

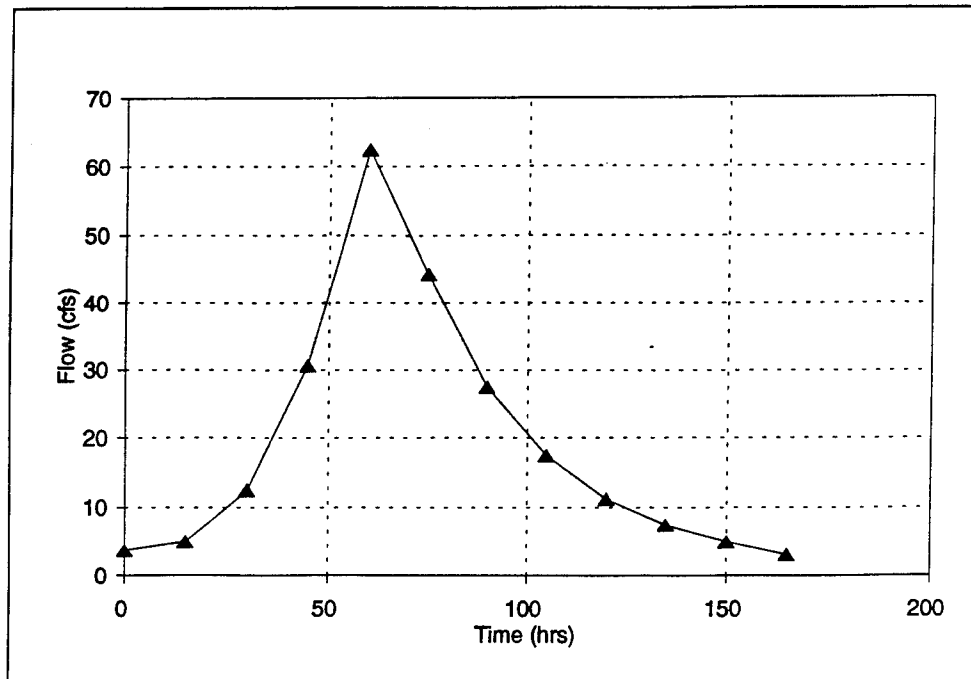


Figure 13. Spring Creek runoff hydrograph

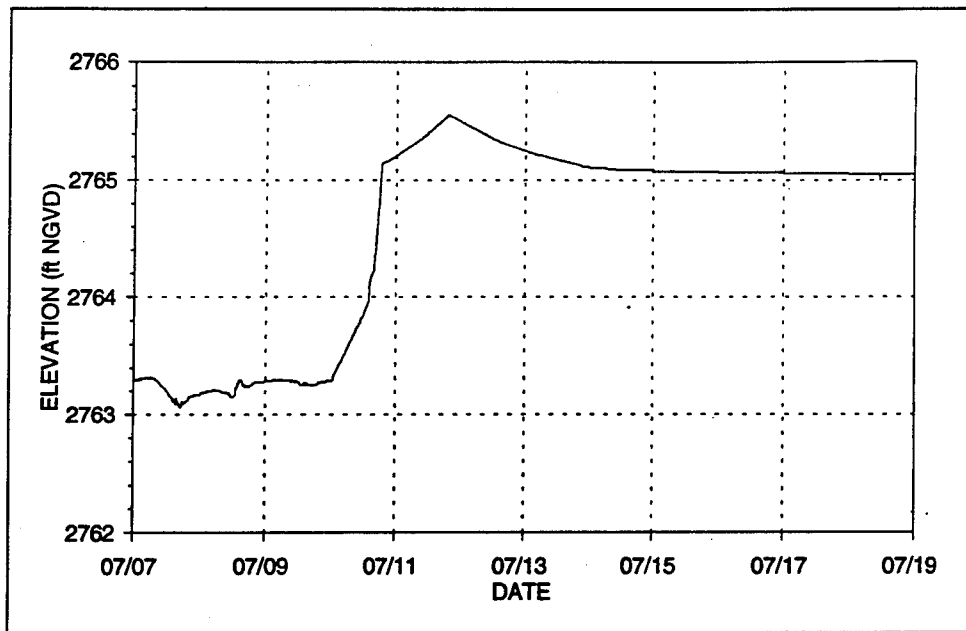


Figure 14. Spring Creek water surface elevations for July 10, 1992, storm event

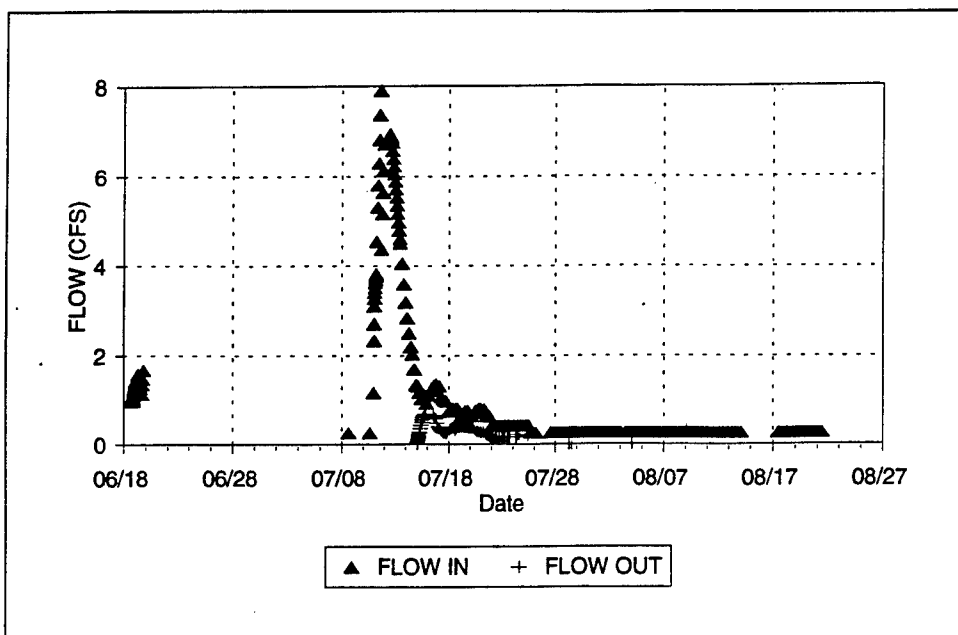


Figure 15. Wetland flows, 1992 sampling period

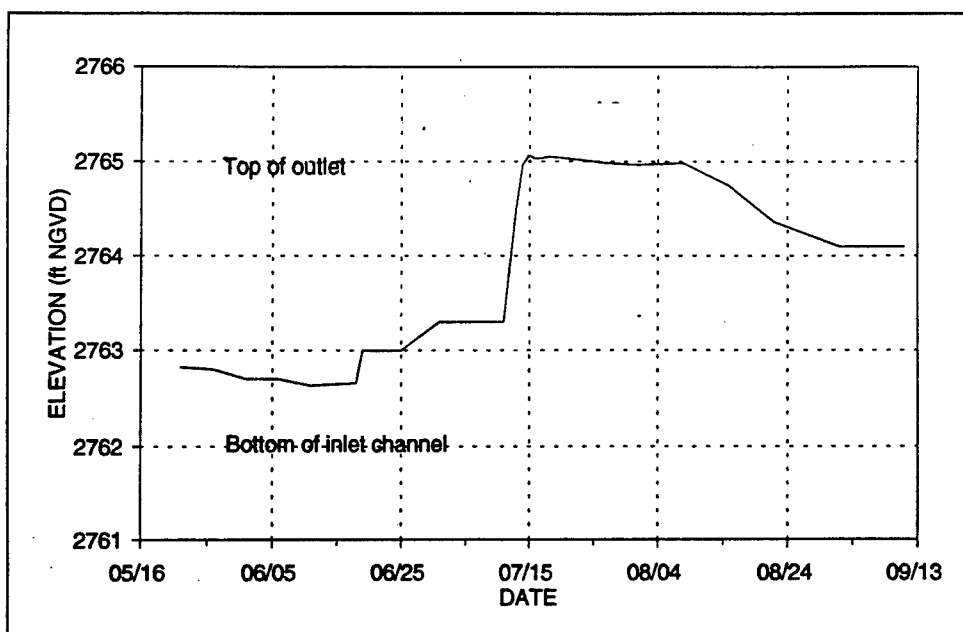


Figure 16. Wetland water surface elevations, 1992 sampling period

Spring Creek and the wetland were monitored until July 7, when the wetland was drawn down to repair extensive erosion damage to the south dike. Upstream and downstream water surface elevations are shown in Figure 17. Sampling stations are shown in Figure 5. Animals cut the cable to the downstream data logger in late June so that the last rise in water levels in the wetland was not recorded. The inflows and outflows, as estimated with the computer program, are shown in Figure 18.

Because Spring Creek remained full for the entire sampling period, flows in the creek could be estimated based on the upstream head and the broad crested weir equation. Estimated flows in Spring Creek are shown in Figure 19.

During dry periods when storm flows were unavailable, water levels in the wetland and Spring Creek were approximately equal. During these times, flow into the wetland replaced evaporation and seepage losses from the wetland. However, the flow was so small it could not be measured. For these dry periods, flow into the wetland was assumed to equal evaporation because no measurement of seepage was available. There was no direct way to determine seepage. Seepage could not be determined from the differences between known inflows and outflows and storage changes because the wetland is tied to the creek which replaces seepage and evaporation losses and keeps the water level in the wetland the same as that in the creek. Although information on soils below the wetland indicates very low permeability, these calculated inflow values for dry periods are low because the effects of seepage are not included. However, these are very small flows, compared with storm flows.

Water Balances

The following water balances were computed based on information described above. The water balance for 1992 is shown in Table 3. As shown, total contributions of water exceeded total withdrawals by 40 acre-ft. This is seen as an increase in wetland storage at the end of the sampling period.

Table 3 Wetland Water Balance, 1992 Sampling Period	
Contributions (acre-ft)	Withdrawals (acre-ft)
Inflow = 71.28	Outflow = 5.92
Rainfall = 16.08	Evaporation = 41.42
Total = 87.36	Total = 47.34

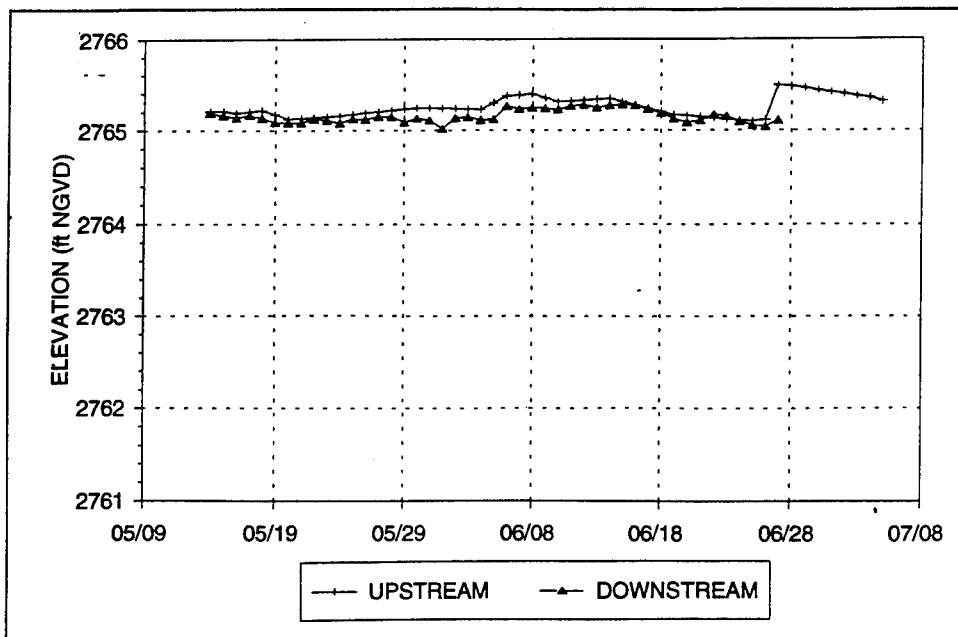


Figure 17. Wetland water surface elevations, 1993 sampling period

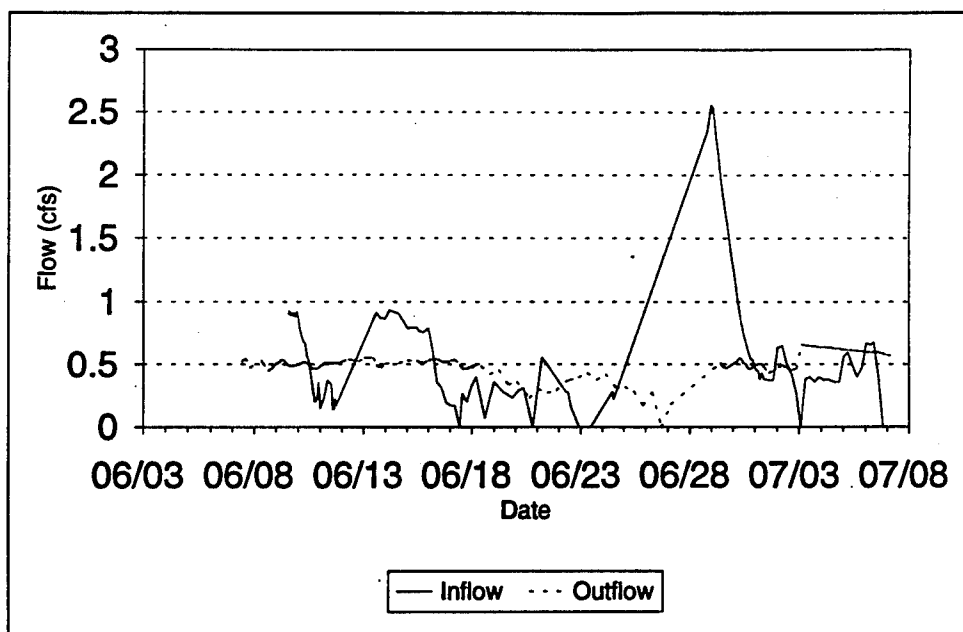


Figure 18. Wetland flows, 1993 sampling period

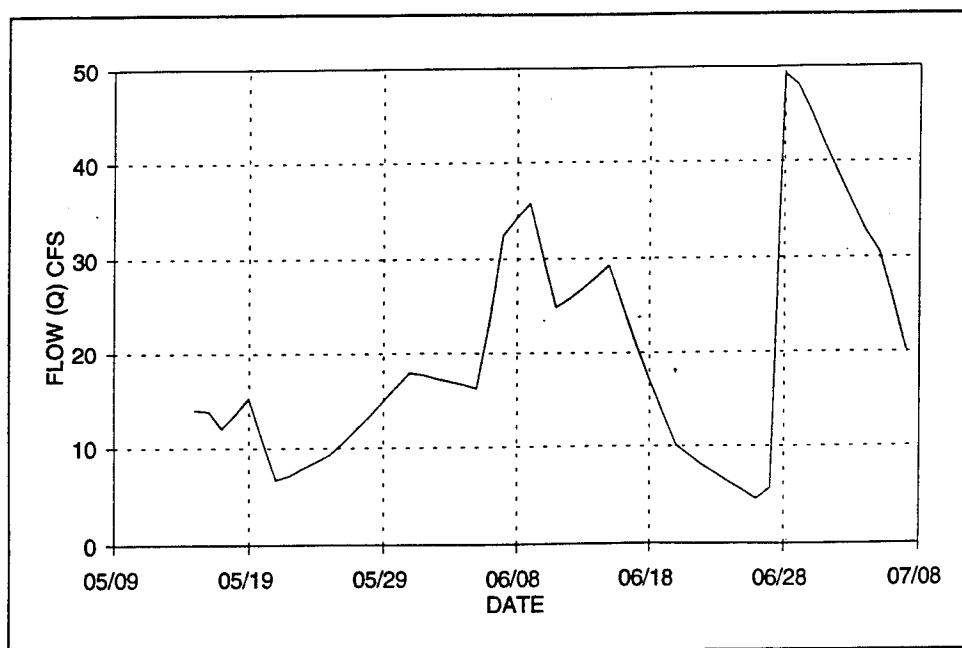


Figure 19. Spring Creek flows, 1993 sampling period

Total flows in Spring Creek for the sampling period were estimated to be 270 acre-ft, of which 200 acre-ft is estimated to have passed over the diversion weir. Therefore, the wetland was able to divert approximately 26 percent of the creek flows. Approximately half of this water was later released back to the creek as either overflows (6 acre-ft) or as draw-down water, water released at the end of the summer (31 acre-ft). After draw-down, approximately 2.3 acre-ft of water remained in the wetland.

The 1993 water balance is shown in Table 4. Evaporation at the site was below normal because of the unusually cool and wet weather.

Table 4 Wetland Water Balance, 1993 Sampling Period	
Contributions (acre-ft)	Withdrawals (acre-ft)
Inflow = 34.39	Outflow = 31.54
Rainfall = 4.56	Evaporation = 8.05
Total = 38.95	Total = 39.59

Although these quantities of water actually flowed through the system, inflow and outflow sampling was aimed at storm events. The actual inflow and outflow volumes sampled were 30.07 and 25.21 acre-ft, respectively.

Total flow in Spring Creek for the 1993 sampling period was estimated at 2,180 acre-ft, of which 2,146 acre-ft passed over the diversion weir, and 34 acre-ft was diverted into the wetland. The wetland was able to divert and

treat less than 2 percent of the available water during the 1993 sampling period.

As is seen in Figures 15 and 18, as well as in the water balances, very little outflow from the wetland occurred. This is because of the control structures in place. With the top of the large diversion weir located at the same elevation as the outlet, water surface elevation in the stream barely exceeds the wetland outlet elevation, leaving little driving force to move the water through the wetland. Also, flow through the culvert is dependent on the tailwater elevation. As the water surface in the wetland rises, flow through the culvert decreases. Very little flow through the culvert occurs when the water surface of the wetland approaches the outlet elevation.

Because flows into the full wetland are so small, the ability of the wetland to divert a significant portion of the creek flow depends on the amount of creek flow available and operation of the wetland. Less creek flow favors greater treatment effectiveness because a greater percentage of the creek flow is diverted through the wetland. In addition, filling the wetland with spring snow melt, as done in spring 1993, reduces the amount of storm water that the wetland can later retain. The wetland was able to divert and treat a significant portion, about one third, of the available flow during the 1992 sampling period, while in 1993 very little of the flow was diverted and treated. This was due to the combination of creek flows and operation. While filling the wetland with early spring snow melt waters may be advantageous for early nesting waterfowl, it is not conducive to treatment of storm waters in Spring Creek.

Water Quality Sampling

During the 1992 sampling period, 365 water samples were collected and analyzed for the following constituents: total suspended sediments (TSS), sulfates (SO_4), total phosphorus (TP), total Kjeldahl nitrogen (TKN), and the herbicides alachlor, aldicarb, atrazine, carbofuran, cyanizol, and 2,4-D (Formal chemical names are given in Appendix A). Mass loadings were calculated by multiplying inflows and outflows by the measured pollutant concentrations. In the 1993 sampling period nearly 300 samples were collected and analyzed for TSS, TKN, nitrite plus nitrate nitrogen ($\text{NO}_2 + \text{NO}_3$), TP, and the herbicide atrazine at both the inlet and outlet. The mass loadings and treatment efficiencies are shown in Table 5 for TSS, TP, TKN, $\text{NO}_2 + \text{NO}_3$ as nitrogen, and SO_4 . Herbicide concentrations were too low for reliable estimates of loadings or treatment efficiencies.

Table 5 Mass Loadings and Removal Efficiencies of Measured Pollutants				
Constituent/year		Inflow Mass kg	Outflow Mass kg	Treatment Efficiency, %
TSS	1992	3,809	668	82
	1993	1,109	431	61
TP	1992	36.5	23.3	36
	1993	33.2	18.8	43
TKN	1992	147.9	133.7	10
	1993	75.3	124.0	-65
NO ₂ + NO ₃ 1993		0.765	0.684	11
SO ₄ 1992		107,648	43,060	60

For 1992, values in the table for outflow mass and treatment efficiency reflect the sum of the mass that exited the wetland during storm events and the mass of pollutants that exited during the draw-down period. The concentration of draw-down water was estimated to be the same as the average outflow concentration. This should provide a conservative estimate since the last measurements at the outflow were lower than the average for most pollutants. Values for mass outflow and treatment efficiency in 1993 are for overflow waters only.

Total suspended solids

TSS removal was good for both years. TSS inflow and outflow concentrations for the 2 years are shown in Figures 20 and 21. As shown in the figures, the outflow concentration remains approximately the same, regardless of inflow concentration. Wetlands can typically reduce suspended sediments concentrations to some lower limit.¹ For this wetland, at its current stage of development, the data indicate that the lower limit of outflow concentration is around 12 mg/L. Base flow and in-lake samples collected in May 1993 had TSS concentrations of approximately 14 mg/L. For suspended sediments, the treatment efficiency is probably more a function of the incoming concentration; i.e., for a runoff inflow concentration of 250 mg/L, treatment efficiency is probably around 95 percent, while treatment efficiencies for a base flow concentration of 14 mg/L would be very low. Because inflow concentrations were higher in 1992, treatment efficiencies were also higher.

¹ R. Kadlec. (1992). Course notes from "Creating and Using Wetland," University of Wisconsin, Madison.

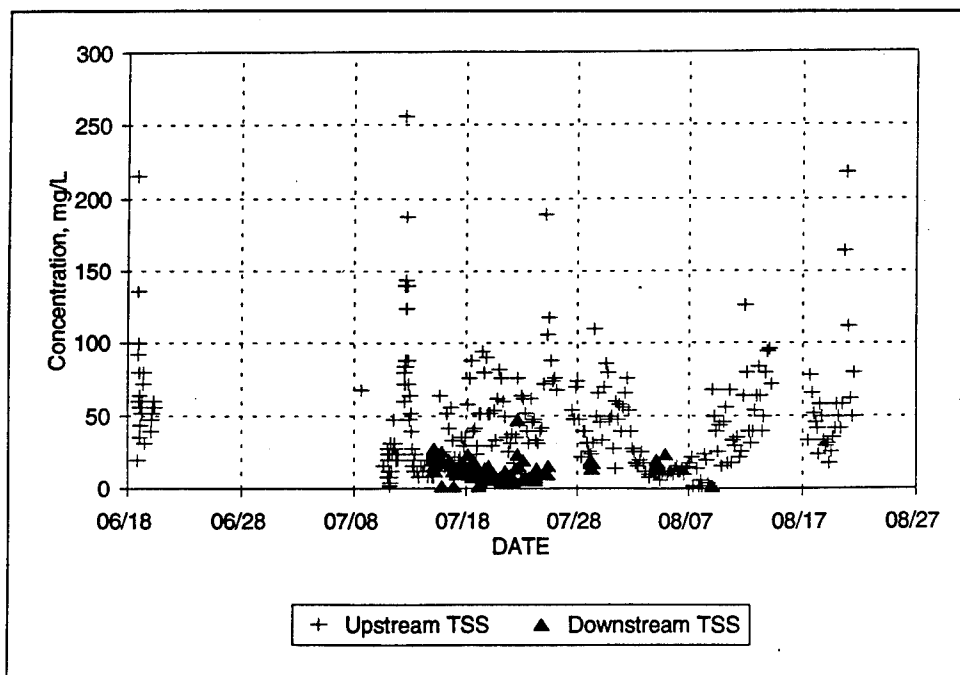


Figure 20. 1992 TSS concentrations

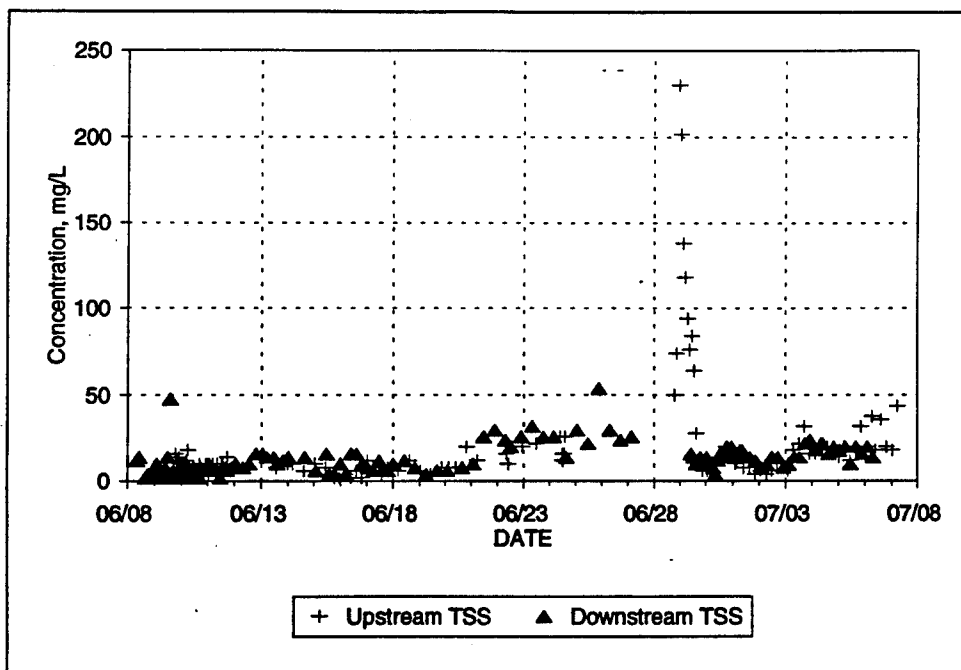


Figure 21. 1993 TSS concentrations

Total phosphorus

The wetland was able to remove approximately 40 percent of the TP load. TP concentrations for the two sampling periods are shown in Figures 22 and 23. Spring Creek base flow samples collected in May 1993 had an average concentration of 0.93 mg/L of TP. During the same time, samples collected at the wetland outlet had a TP concentration of 0.68 mg/L. Samples collected from the lake had a concentration of 0.90 mg/L. The bulk of TP removal is probably due to settling and burial of particulate matter with some vegetative uptake.

Nitrogen

TKN is the summation of ammonia nitrogen and organic nitrogen. NO_2 and NO_3 make up the inorganic portion of nitrogen, not in the form of ammonia, and together with TKN comprise most of the nitrogen in solution. The wetland was not effective in the removal of nitrogen from the system. Mass balances indicated only 10 percent removal of TKN in 1992, and the wetland was a net exporter of TKN in 1993. Concentrations of TKN for 1992 and 1993 are shown in Figures 24 and 25, respectively.

As is shown in Figure 24, concentrations of TKN remained essentially unchanged through the wetland in 1992. The calculated 10 percent removal may or may not have actually been realized. It is well within the total error of the measurements and calculations.

As shown in Figure 25, inflow concentration of TKN remained nearly constant over the 1993 sampling period, at approximately 2 mg/L. The concentration of TKN at the outflow was originally 6 mg/L and fell throughout the course of the sampling to near inflow levels by the end of the sampling period. Base flow samples collected in May indicated that the inflow concentration was 1.82 mg/L and the outflow concentration was 2.83 mg/L. At the same time, the lake concentration of TKN was 3.24 mg/L. The data indicate that the wetland had a large TKN loading early in the spring, before sampling began, and that the gradual reduction in outlet TKN values was due to dilution of the originally high values. Fertilizer was applied to the sides of the diversion channel in spring of 1992 to promote grass growth. Some portion of this fertilizer may have washed into the wetland during the previous year, or during spring thaw. The continued decline of ammonia concentration at the outlet is probably due to dilution of the original input of ammonia nitrogen from fertilizers.

While the wetland was a net exporter of TKN, the mass of $\text{NO}_2 + \text{NO}_3$ as nitrogen was slightly reduced by the wetland (11 percent) though the average concentration actually slightly increased (Figure 26). This would indicate that little if any of the TKN is being converted to nitrate or nitrite by nitrification.

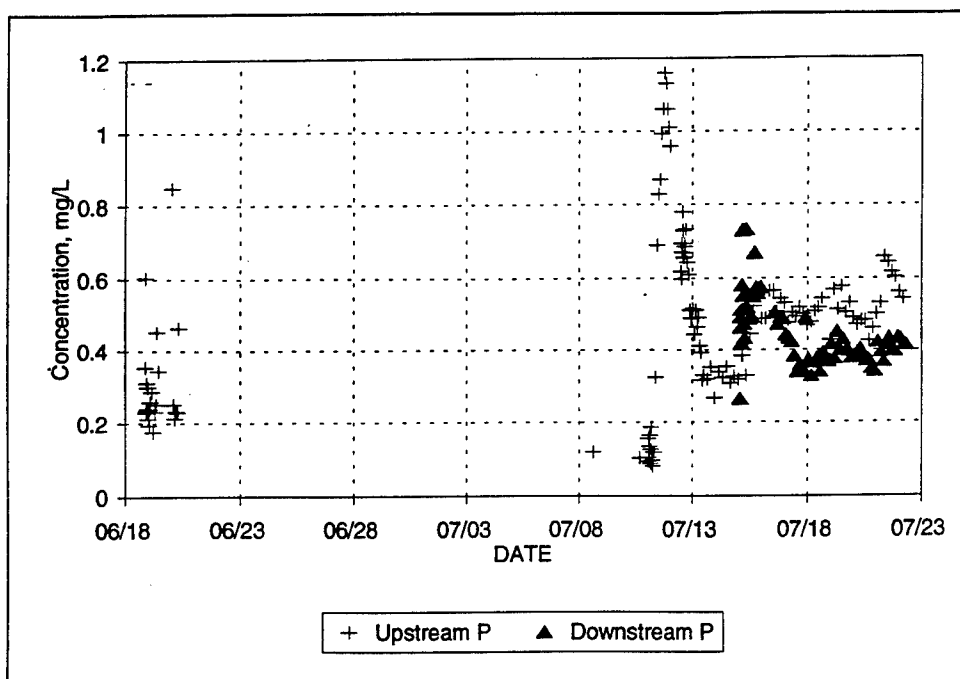


Figure 22. 1992 TP concentrations

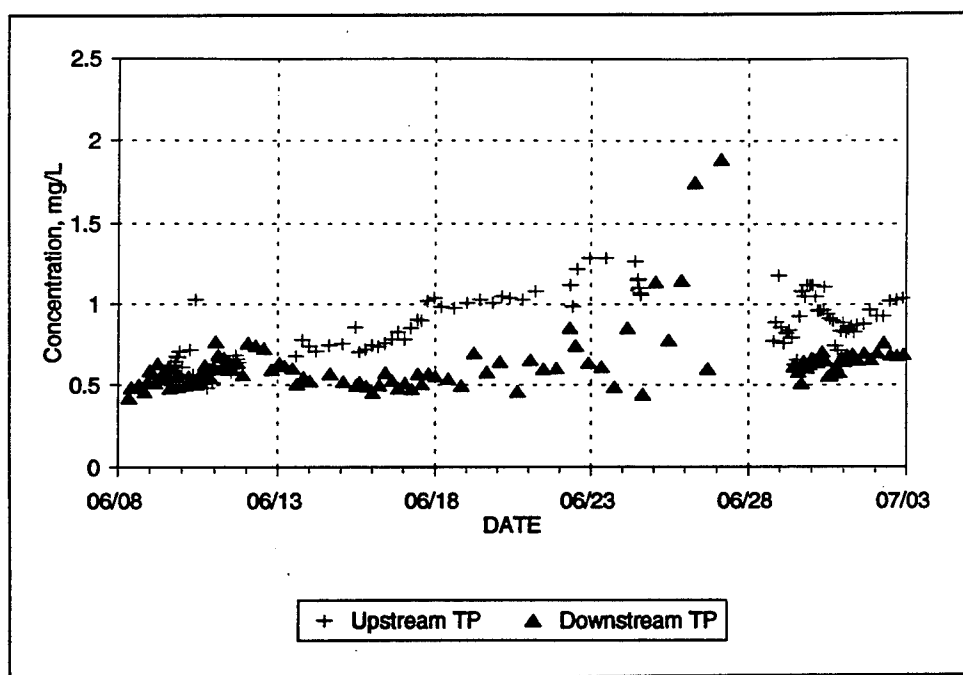


Figure 23. 1993 TP concentrations

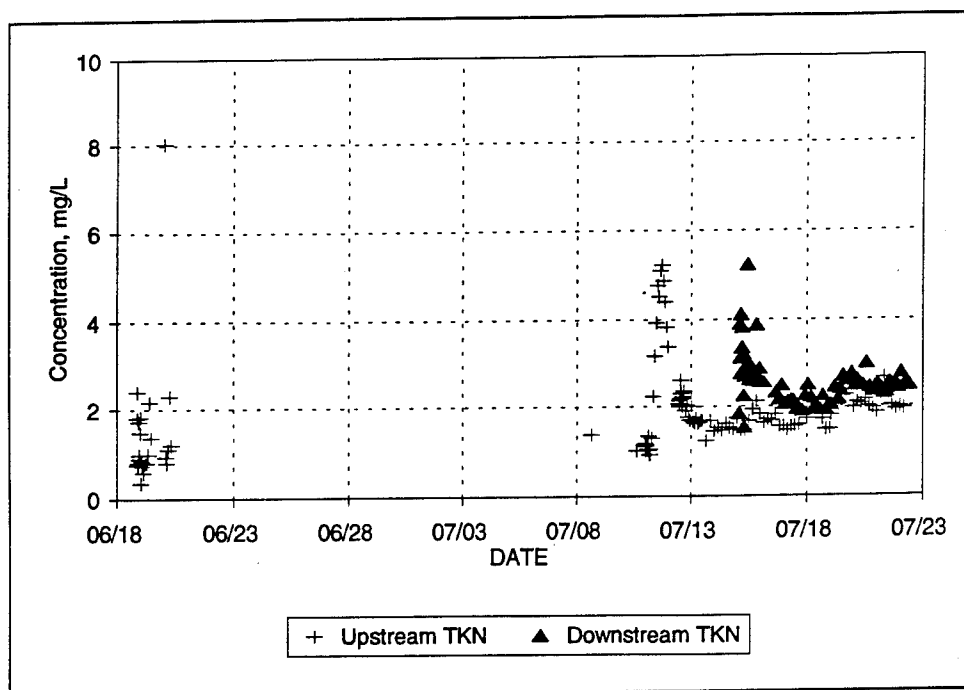


Figure 24. 1992 TKN concentrations

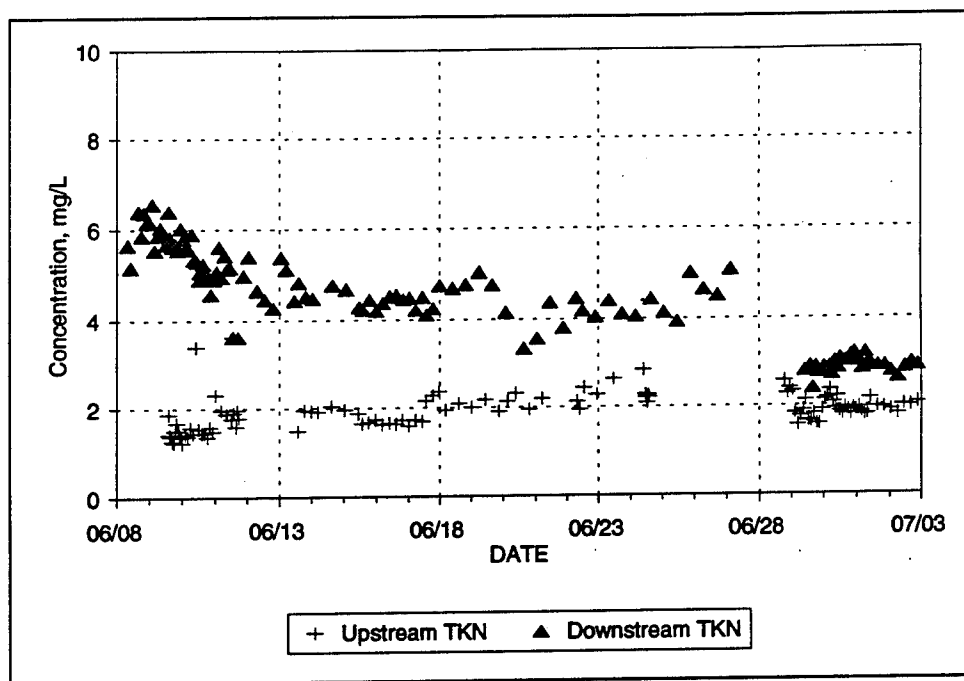


Figure 25. 1993 TKN concentrations

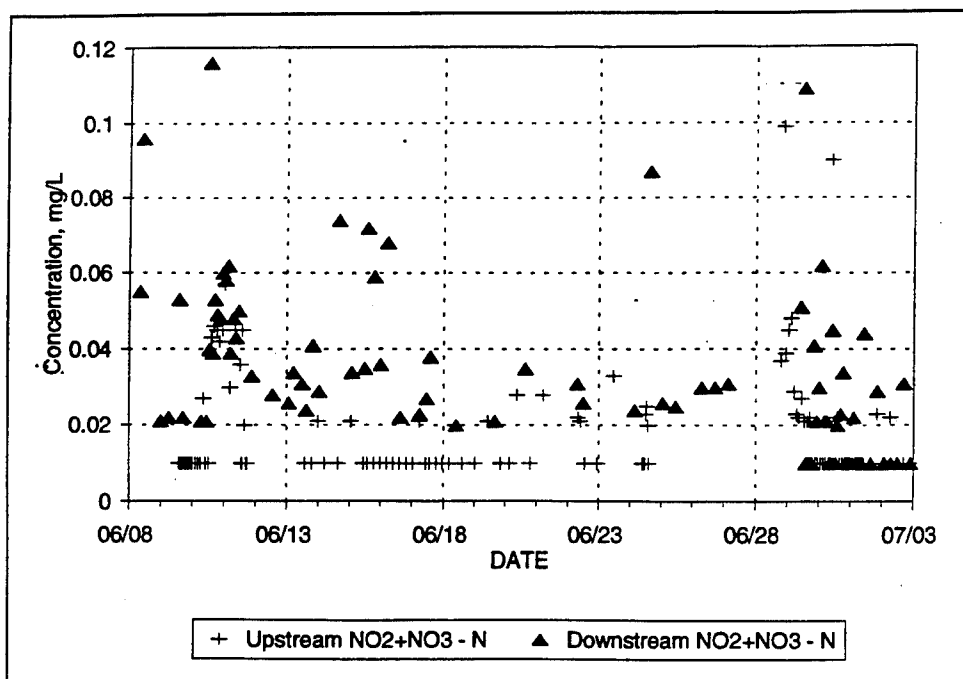


Figure 26. $\text{NO}_2 + \text{NO}_3$ nitrogen concentrations

Removal of nitrogen in wetlands is accomplished by plant uptake and the processes of nitrification and denitrification. Nitrification of NH_4 occurs in an oxygen-rich environment. Denitrification occurs in an oxygen-deficient system, i.e. in the wetland detritus and sediments. Since this wetland is newly constructed, there is little or no detritus at the bottom of the wetland. Hence, little or no denitrification can occur. Although this system currently does not remove nitrogen, nitrogen removal should improve as the wetland matures. Still, the treatment efficiency of the wetland for nitrogen may not be high because inflow concentrations are relatively low.

Sulfate

Sulfate is a dissolved constituent that is normally found in the form of salts. Very high concentrations of sulfates and other dissolved salts are found in the water in the region due to the high evaporation rates which tend to concentrate the salts naturally found in solution. A large SO_4 loading was delivered to the wetland during the first measurable rainfall event. The mass balance computations indicate 60 percent removal of SO_4 . However, it is highly questionable that any treatment of SO_4 actually occurred. Most of the mass of SO_4 came into the wetland during the first storm event of the year. Although the amount of water contributed to the wetland from this storm event was low, the concentrations of SO_4 were very high, up to 17,000 mg/L. Inflow and outflow concentrations of SO_4 are shown in Figure 27. The reduction in SO_4 is probably due to small seepage losses between the first two storm events, which because of the high concentrations, caused large losses of

mass. Later storms functioned to dilute the very high concentrations, which is seen in Figure 27 as an increase in concentration from inflow to outflow.

Herbicides

While information from the local soil conservation district indicated that a relatively high percentage of farmers in the region use herbicides, concentrations of herbicides found in inflow samples were very low for both the 1992 and 1993 sampling periods. The only significant concentrations of herbicides were found during the first storm event after an extended dry spell in 1992. Inflow and outflow concentrations for the six herbicides tested for in 1992 are shown in Appendix B. In many of the samples analyzed, no herbicides were detected. In Appendix B, values below detection limits are shown as zero. Because so many of the samples were below detection limits it is useful to look at the number and percentage of "hits," samples that had measurable quantities of the herbicide, for each chemical. The number of hits for inflow and outflow samples and the maximum concentrations for each herbicide are shown in Table 6. Herbicides are listed in decreasing order of prevalence at the wetland inflow.

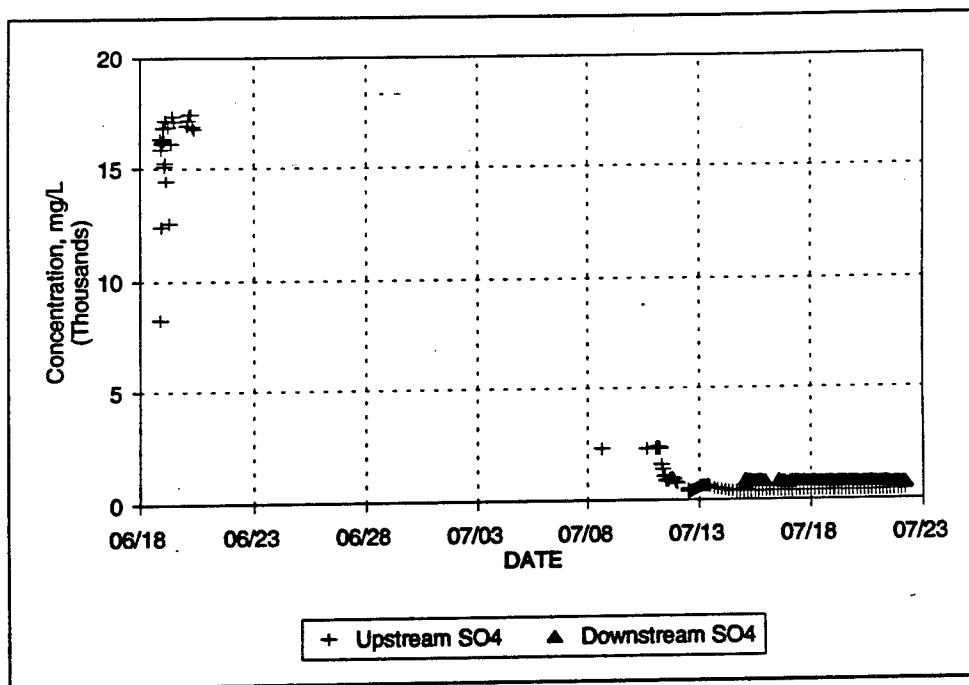


Figure 27. 1992 SO₄ concentrations

As shown in Table 6, carbofuran, 2,4-D, and cyanizn are prevalent herbicides in the area. Atrazine also appears to be an important chemical, while alachlor and aldicarb are seemingly less important. Although aldicarb was not prevalent, relatively high concentrations of the herbicide were detected during the first storm event.

Table 6 Prevalence and Persistence of Herbicides, 1992 Sampling Period									
Herbicide	Detection Limit $\mu\text{g/L}$	Inflow			Max Conc. $\mu\text{g/L}$	Outflow			Max Conc. $\mu\text{g/L}$
		No. of Samples	No. of Hits	% Hits		No. of Samples	No. of Hits	% Hits	
Carbofuran	0.1	128	58	45	1.5	71	21	30	2.7
2, 4-D	1.0	128	52	41	34.0	71	13	18	10.0
Cyanizen	0.1	110	42	38	1.3	47	11	23	0.4
Atrazine	0.1	24	8	33	0.4	18	7	38	0.3
Alachlor	0.1	128	18	14	0.6	71	6	8	1.0
Aldicarb	0.1	128	8	6	10.0	71	8	11	8.0

For most of the herbicides, the highest concentrations were seen in the first runoff event. This would be expected because the herbicides had time to accumulate on the fields without being flushed. These data indicate that these high concentrations never exit the wetlands.

Testing for atrazine during the 1993 sampling period produced very few positive samples at the inflow and no positive samples at the outflow. Even when atrazine was detected, the concentrations were very low, on the order of $0.1 \mu\text{g/L}$. Although no atrazine was found at the outlet, it is impossible to draw any conclusions as to treatment effectiveness of the wetland for atrazine.

The timing of the peak concentrations at inflow and outflow indicates a detention time of about 4 days, which is probably insufficient for significant biodegradation of herbicides. In addition, this wetland is still fairly undeveloped, lacking thick vegetation and bottom detritus. Treatment of herbicides may also improve in this wetland as it develops.

Discussion

The potential effect of the wetland on the water quality of the lake is limited due to the design of the water control structures and the operation of the wetland for waterfowl nesting. Because of the wetland design, only a small portion of storm flows pass through the wetland after the wetland is full. In addition, filling the wetland with spring snow melt water to allow for early waterfowl nesting takes away storage capacity of the wetland that could be used during summer storm events. As seen in 1992, during dry years the wetland has the ability to capture, detain, and treat a significant portion of Spring Creek flows. The potential for the wetland to improve water quality in Spring Creek and Bowman-Haley Lake would be increased if the wetland

were operated more specifically for this purpose. The best way to operate the wetland for water quality improvement would be to keep most of the storage area in the wetland available for storm events. After a storm event, water that entered the wetland could be held until another storm was anticipated and then released to provide storage for the next event. This type of operation would maximize the amount of water treated and the hydraulic retention time for each storm event. An alternative measure would be to provide for a greater difference in head between the inlet and outlet structures to increase flow through the wetland. Although this would reduce the hydraulic retention time of the wetland, it would increase the amount of pollutants removed from the stream by increasing the percentage of storm waters that actually pass through the wetland. The removal of pollutants that are already being effectively removed, suspended particles, should not suffer from a reduced hydraulic retention time, though the removal of dissolved constituents could.

Other Water Quality Data

During a May 1993 field trip to the site, spot samples of temperature, dissolved oxygen, and flow were taken. Temperature and dissolved oxygen readings were taken with a YSI dissolved oxygen meter. The meter was dry-air calibrated before dissolved oxygen measurements were taken. Flows at the outlet pipe were calculated by measuring flow velocity with a Marsh McBurney pressure probe, measuring depth and width of flow, and then calculating flow as area times velocity. The flow at the time was from base flow in Spring Creek. A summation of the sampling results is given in Table 7.

Table 7 Spot Sampling of Spring Creek Wetland, 1993				
Location	Date	Temp. °C	Dissolved Oxygen	Flow cfs
Upstream inlet	May 12	-	-	-
Outlet	May 12	-	-	0.30
Upstream inlet	May 13	21.7	-	-
Outlet	May 13	20.7	-	-
Upstream inlet	May 14	20.5	-	-
Outlet	May 15	-	-	0.35
Upstream inlet	May 17	14.0	8.00	-
Outlet	May 17	14.8	8.25	-

As is shown in Table 7, dissolved oxygen in the wetland at the time of sampling was near the saturation concentration, 10.3 at 14.0 °C (Thomann

and Mueller 1987), at both inlet and outlet. Because the wetland is shallow and exposed to the prevalent winds, it can be anticipated that the dissolved oxygen concentration in the wetland will typically be near saturation concentration. Most wetlands have an anoxic layer of sediments and/or water on the wetland bottom, which is an important component in water quality improvement. It is not known if this wetland has developed such a layer. However, with the lack of vegetation and potential for reaeration at the site, the wetland may or may not develop this layer.

Wetland Retention Time

A dye study was conducted to estimate retention time for the wetland. One liter of Rhodamine WT 20-percent solution was mixed in approximately 32 gal of water and poured in at the downstream side of the inlet culvert at 1104 hr on May 12, 1993. The first sampling point was located at the point where the inlet channel entered the main wetland body (Figure 5). The second sampling point was located in the outlet pipe (Figure 5). A Turner Designs model 10-AU-005 fluorometer, with internal data logger and flow-through cuvette, was used in conjunction with a submersible bilge pump to sample the dye cloud. Both the fluorometer and pump were powered by a deep cycle marine battery. Because a battery would not power both instruments overnight, some gaps appear in the data.

The fluorometer was previously calibrated in the laboratory. For concentrations over 100 $\mu\text{g/L}$, blocking of fluorescence occurs and a calibration curve for the concentration range between 100 and 500 $\mu\text{g/L}$ was developed. The equation for the calibration was:

$$\text{Concentration } (\mu\text{g/L}) = \text{Reading}^{1.04}/1.127$$

At concentrations above 500 $\mu\text{g/L}$, blocking becomes so severe that the reading will begin to drop. In addition to the calibration curve for concentrations between 100 and 500 $\mu\text{g/L}$, a temperature correction factor n was also determined in the laboratory. The correction factor was determined to be -0.027 for this fluorometer, which is applied in the following equation (Baker and Holley 1988):

$$F_{23.0} = F_T e^{[n(23.0T)]}$$

where

$$F_{23.0} = \text{fluorescence at } 23.0^\circ\text{C}$$

$$F_T = \text{fluorescence measured at temperature, } T$$

All field measurements were corrected to 23.0 $^\circ\text{C}$.

Data collection at the first sampling site began on May 12 at approximately noon and ended on noon of May 15. Data were logged every 30 sec. The peak concentration of 174 $\mu\text{g/L}$ occurred at the first site after an elapsed time of 10 hr.

Data collection at the second sampling site began on May 15 at approximately noon and ended on May 17 at 0930. Data were logged every 10 min. The peak concentration of 4.83 $\mu\text{g/L}$ occurred 109 hr after the beginning of the test. The time of travel, at the measured flow, was 109 hr or about 4.5 days. Water quality measurements also indicate that the retention time of storm hydrographs in the wetland is on the order of 4.5 days.

While a hydraulic retention time of 4.5 days is sufficient for removal of suspended sediments, it is probably not adequate for removal of herbicides.

Sediment Accretion

Results of sampling the Plexiglas sediment disks are shown in Table 8. The disks represent sediment accumulation during the 1993 sampling period. As shown in this table, the overall average accumulation of sediments for the wetland for 1993 was 3.0 mm. Accumulation varied widely from a high of 12.8 mm to a low of 0.0 mm. The highest sediment accumulation was recorded where the inlet channel emptied into the wetland, and the lowest accumulation was recorded in areas that were infrequently inundated.

The mass of sediments on the disks ranged from 0 to 94 g and averaged 13.1 g of dry material. The average areal loading of dry materials was 1.31 kg/m^2 . The sediments on the disks were primarily inorganic, being comprised of 7.4 percent organic (volatile) material. The density and specific weights of the materials indicate that the bottom sediments are largely uncompacted.

The results of sampling the feldspar pads are presented in Table 9. The pads represent 2 years of accumulated sediments. The average accumulation of sediments on the pads was 9.9 mm, and ranged from 4.9 to 16.9 mm. Testing of selected samples indicated that the areal loading of sediments for the 2 years was 8.4 kg/m^2 . The density of the combined sediments was three times greater than that of the 1993 samples, indicating that significant compaction had occurred during the winter drawdown of the wetland in 1992. Analysis for volatile solids of these samples also indicated that the sediments were primarily inorganic.

Applying the estimated areal loadings of sediments over the entire wetland for the 2 years equates to 125,000 kg (13.4 tons) of material in 1993 and 1,322,000 kg (142 tons) for the two combined years. With the average bulk density being 0.5 g/cm^3 for 1993 and 1.5 g/cm^3 for the two combined years,

Table 8
Sediment Samples from Plexiglas Disks

Disk #	Avg. Sed. Depth mm	Dry Sed. Weight g	Areal Accum. kg/m ²	% Organic	Areal Organic Accum kg/m ²	Bulk Density Solids g/cm ³	Bulk Spec. Weight Solids lb/ft ³
1	0.0	0.0	0.00	-	0.00	-	-
2	0.0	0.9	0.09	<4.0	0.00	-	-
3	8.3	56.8	5.68	8.8	0.50	0.7	42.9
4	2.6	3.6	0.36	15.0	0.05	0.1	8.4
5	6.4	17.5	1.75	7.5	0.13	0.3	17.2
6	0.3	0.8	0.08	13.3	0.01	0.3	16.6
7	0.0	0.5	0.05	<4	0.00	-	-
8	1.8	13.8	1.38	5.9	0.08	0.7	46.7
9	0.5	1.4	0.14	4.6	0.01	0.3	16.6
10	3.6	17.7	1.77	4.5	0.08	0.5	30.5
11	4.3	1.5	0.15	7.4	0.01	0.0	2.1
12	0.1	2.0	0.20	14.7	0.03	2.0	123.1
13	0.0	0.3	0.03	<4	0.00	-	-
14	7.7	23.5	2.35	9.2	0.22	0.3	19.1
15	5.5	12.3	1.23	10.8	0.13	0.2	13.9
16	0.0	0.0	0.00	-	0.00	-	-
17	0.2	1.9	0.19	11.4	0.02	0.9	57.8
18	0.0	1.3	0.13	<4	0.00	-	-
19	-	-	-	-	-	-	-
20	12.8	93.8	9.38	12.3	1.15	0.7	45.8
Avg.	3.0	13.1	1.31	7.4	0.13	0.5	33.9

the material would occupy a space of 274 m³ (0.22 acre-ft) for 1993 and 889 m³ (0.728 acre-ft) for both years combined.

Estimates of TSS contained in the wetland indicate that only 3,200 kg of material was retained in 1992 and 700 kg in 1993, or a total of 3,900 kg of deposited materials. An obvious discrepancy exists between the TSS and sediment accretion data sets. During the 2-year life of the wetland, erosion of the side slopes of the inlet channel, southern dike, and eastern bank has been

Table 9 Sediment Samples from Feldspar Pads						
Pad #	Avg. Sediment Depth mm	Dry Weight g	Areal Accum kg/m ²	% Organic	Bulk Density Solids g/cm ³	Bulk Specific Weight Solids lb/ft ³
RP 1	8.7					
RP 2	16.4					
RP 3	4.9	32.9	9.3	0.0	1.9	118.3
RP 4	6.2					
RP 5	8.9					
RP 6	16.9					
RP 7	7.0	26.2	7.4	12.0	1.1	66.0
AVG	9.9		8.35			92.1

extensive. Areas of high erosion are shown in Figure 28. Side slopes of the inlet channel are now nearly vertical. The southern dike was nearing failure by the end of the 1993 sampling period and had to be repaired and covered with riprap. It is believed that some portion of the eroded material is being redistributed about the wetland. For this reason, it is believed that the sediment accretion data collected are unreliable as a measure of the quantity and distribution of settling of incoming suspended sediments or of the measure of the buildup of organic sediments in the wetland.

The distribution of sediments (Figure 28) is consistent with the explanation that sediments eroded at the wetland site are overshadowing the effects of settled incoming materials. Sediment accretion at each sampling site is shown in Figure 28. (Measurements on the feldspar pads are contained within parentheses. All other measurements are from the Plexiglas disks.) Areas of erosion are the inlet channel, the high east bank, and the eastern part of the south dike. In large, the pads and disks located nearest these areas encountered the most sediment accumulation.

The estimates of yearly accretion, 4.5 mm/year on the feldspar pads and 3.0 mm/year on the sediment disk, fall on the low side of the range of inorganic sediment accretion measurements in wetlands. Johnston (1991) reviewed available literature and reported sediment accretion rates of inorganic sediments in wetlands ranging from -0.6 cm/year to 1.3 cm/year. At the current rate of infilling, the wetland can be expected to function for a long time as a wildlife habitat and as a water treatment system. With an average depth of 0.86 m, the wetland would require nearly 200 years to fill.

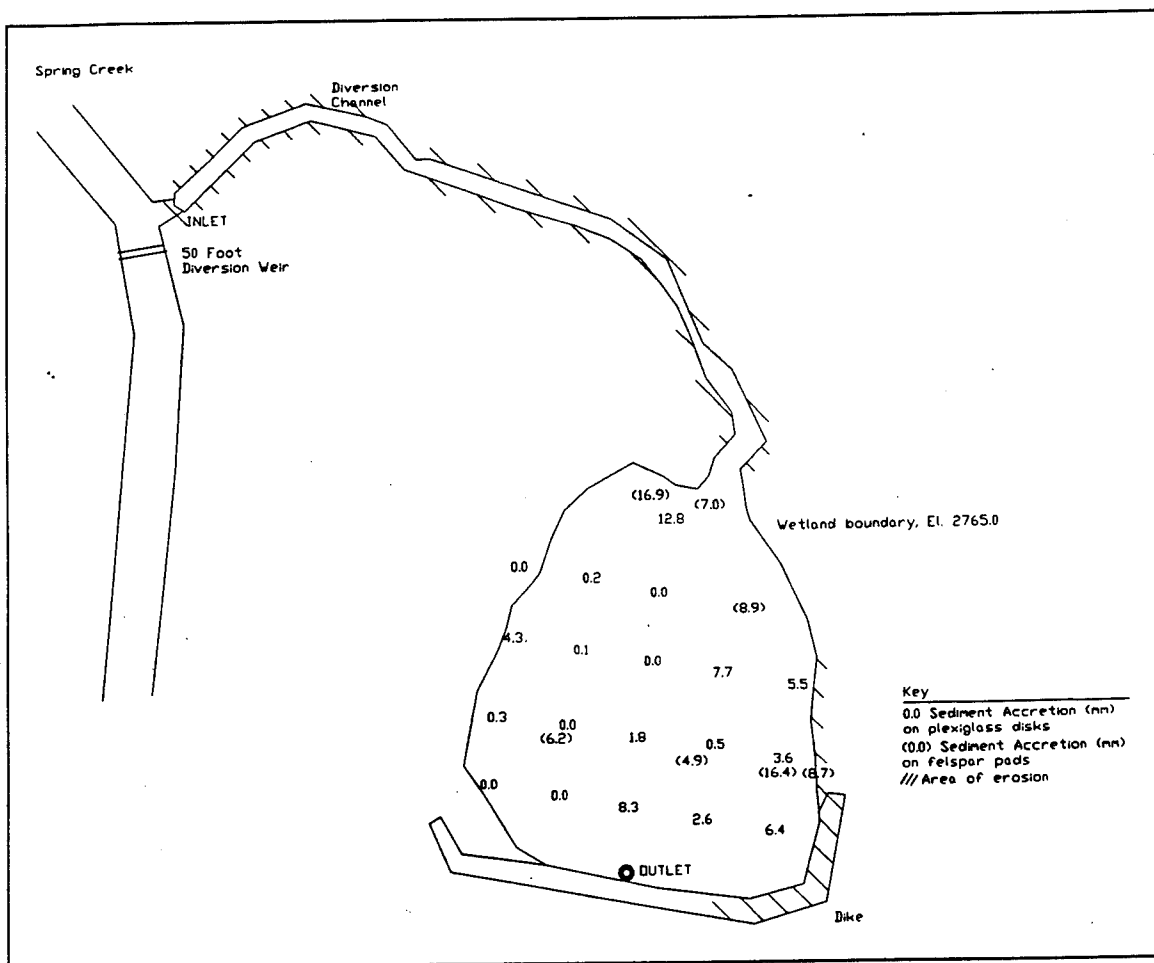


Figure 28. Sedimentation patterns in the Spring Creek wetland

5 Conclusions

The Spring Creek wetland effectively removed suspended solids (62 to 85 percent) and to a lesser extent total phosphorus (36 to 43 percent) from waters diverted to the wetland. Removal of particulate bound phosphorus through suspended solids removal probably accounts for most of the total phosphorus removal.

Removal of nitrogen in the forms of TKN and $\text{NO}_2 + \text{NO}_3$ in the wetland was poor during both sampling periods. Removal of TKN in 1992 was only 10 percent, and the wetland exported TKN in 1993. Removal of $\text{NO}_2 + \text{NO}_3$ as nitrogen was only 11 percent. The addition of fertilizer to the banks of the inlet channel in the spring of 1992 may have skewed nitrogen measurements. The removal of nitrogen is expected to improve as the wetland matures.

Testing for herbicides yielded inconclusive results because of the very low concentrations of herbicides present. No estimates of treatment efficiencies could be made. If herbicides are the intended pollutant for treatment, then it is important to capture and retain the first storm event after spring application. Events after extended dry periods may also be important.

Newly constructed wetlands lack the lush aquatic vegetation and resulting buildup of bottom detritus of mature wetlands. The stems and detritus of aquatic plants provide a substrate for the complex wetland biological community, which is important in the removal of many nonpoint source pollutants. Aquatic vegetation was sparse in the Spring Creek wetland during the study period (1992 and 1993). Without the anoxic wetland substrate and periphyton community, several key biogeochemical reactions do not occur in the wetland. This can affect both nutrient and herbicide removal. Removal of nonpoint source pollutants should improve as the wetland matures. Once the wetland matures, the hydraulic retention time of the wetland will become the limiting factor in pollutant removal efficiencies. Testing indicates that the hydraulic retention time is probably adequate for suspended sediments and nutrient removal but is insufficient for the removal of herbicides.

Design and operation of control structures at the Spring Creek wetland limit the water quality enhancement function of the wetland. Design of the wetland with the top of the outlet structure at the same elevation as the inlet structure deters flow into the wetland because of a lack of hydraulic head.

Most of the base flow is routed through the wetland, and most of the storm flows bypass the wetland once the wetland is full. Filling the wetland in the spring to provide waterfowl nesting habitat reduces storage capacity and results in fewer storm events being diverted into the wetland.

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Appendix A

Chemical Formulations of Herbicides

2,4-D : 2,4-dichlorophenoxyacetic acid;

Atrazine : 2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine

Alachlor : 2-chloro-2',6'- diethyl-N-(methoxymethyl)acetanilide

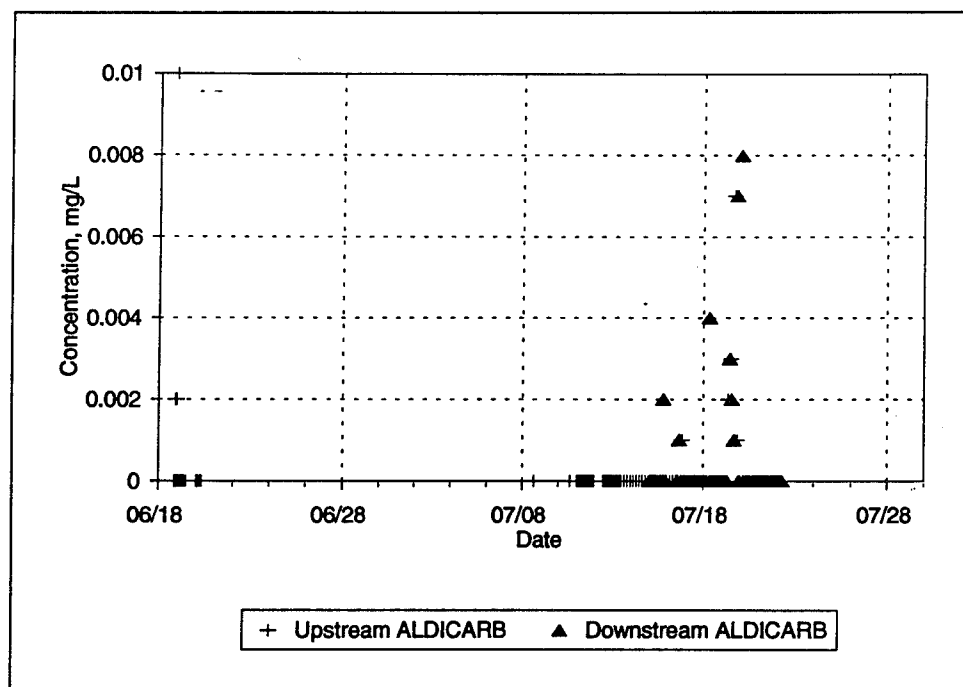
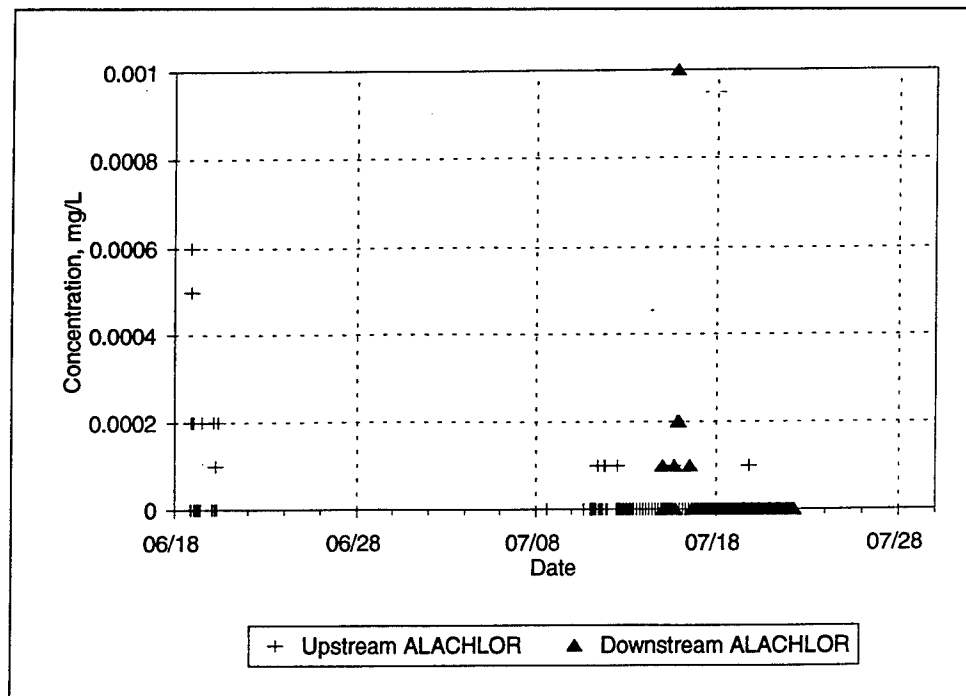
Carbofuran : 2,3-dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate

Cyanazine : 2-[[4-chloro-6-(ethylamino)-s-triazine-2-yl]amino]-2-methyopropionitrile

Aldicarb : 2-methyl-2(methylthio)propionaldehyde-O-methylcarbamoyoxime

Appendix B

Herbicide Concentrations in Inflow and Outflows, 1992



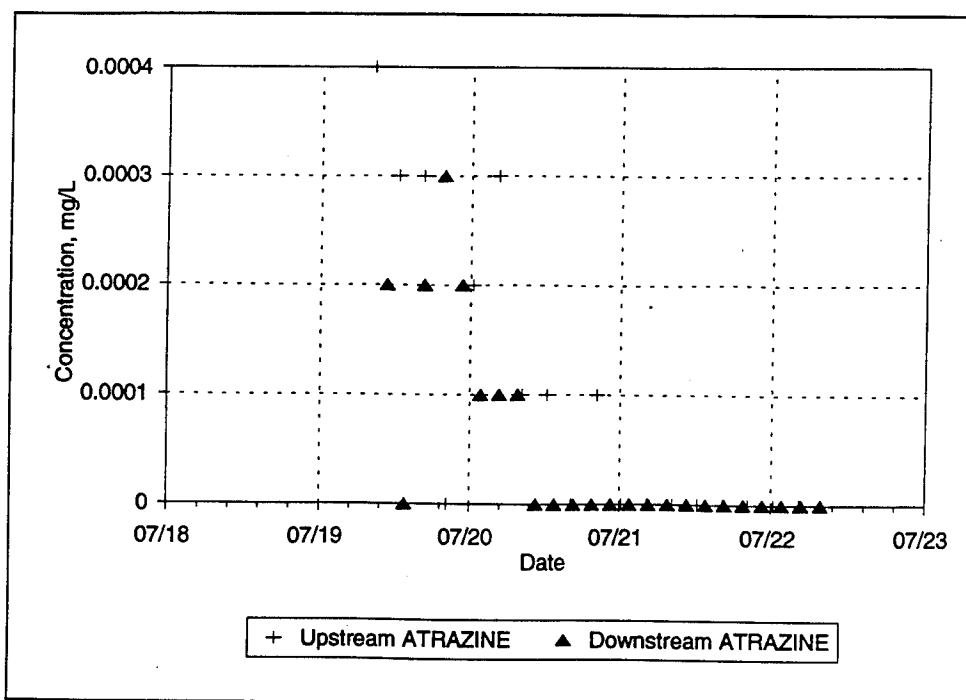


Figure B3. Atrazine concentrations

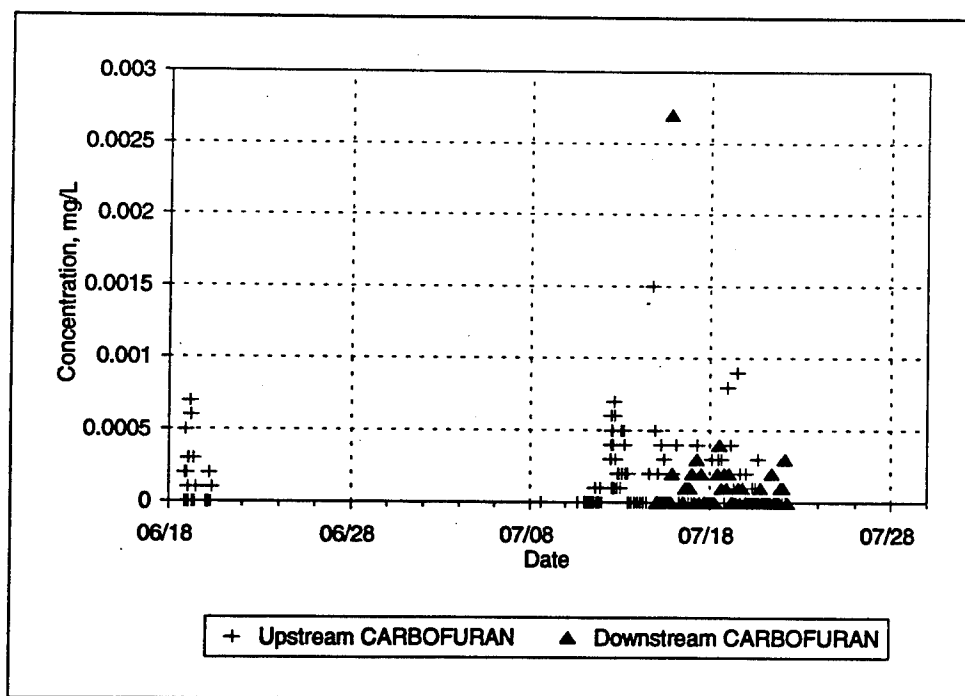


Figure B4. Carbofuran concentrations

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13. ABSTRACT (Maximum 200 words) Bowman-Haley Reservoir is a flood control and water supply reservoir located in the southwest corner of North Dakota. The popular reservoir has suffered from a variety of water quality problems including excess suspended sediments and nutrients. As part of an overall watershed management program, a 24-acre wetland was constructed along Spring Creek, a major tributary into the reservoir. The wetland was intended to remove nonpoint source pollutants from Spring Creek storm flows. Constructed on U.S. Army Corps of Engineers lands by Ducks Unlimited, the wetland was also to serve as waterfowl nesting and resting habitat. During its first 2 years in operation, the wetland was monitored for its ability to remove sediments, nutrients and herbicides from inflows originating from Spring Creek. Results of the monitoring indicated that the wetland was able to effectively remove suspended sediments and, to a lesser degree, total phosphorus. The wetland was ineffective in the removal of nitrogen. Because of the concentrations of herbicides encountered, no estimates on treatment effectiveness could be made. The ability of the wetland to treat nonpoint source pollutants was hampered by the newness of the wetland and by the construction and operation of the wetland to facilitate waterfowl use.				
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